Rencontre GDR FEUX/GFC 2018

Modélisation et expérimentations en combustion et incendies

Reconstruction 3D et résolue en temps du champ de température en face arrière d'un matériau composite soumis au feu

Gillian Leplat[1], Yves Le Sant[2], Philippe Reulet[1] & Thomas Batmalle[1]

[1]**DMPE:** Multi-Physics for Energetics Department

[2]**DAAA:** Aerodynamics, Aeroelasticity and Aeroacoustics Department

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phy sics of fire

ThermoSolEx

FUTURE SKY SAFETY

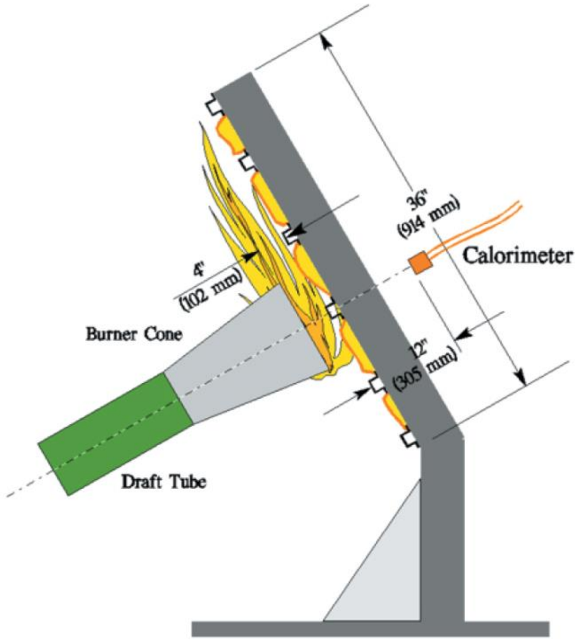
Outline

- Context: Fire Safety Science
- Experimental approach
  - *FIRE facility*
  - *DIC code (FOLKI_D)*
  - *Lagrangian tracking in IR images*
- Results
  - *Metallic panel*
  - *Composite laminate*
- Conclusion

Context: Fire Safety Science

Aviation safety regulation: burnthrough resistance of aircraft structures

Burnthrough test: what does it consist of ?



kerosene burner @ DGA Techniques Aéronautiques

// Aircraft with a passenger capacity of 20 or greater must be constructed so that they are burnthrough-resistant. This means that for a period of at least four minutes, flame penetration through materials from the lower half of the airplane fuselage into the cabin must be prevented. // **FAR 25.856(b) [Amdt. 25-111, July 31th, 2003]**

Context: Fire Safety Science

Fire behaviour of composite materials

Multi-physics problem with coupled phenomena

STATE OF THE ART

Fire
- Fluid dynamics
- Two-phase flows
- Premixed or diffusion flames

Interface
- No coupling
- Constant heat flux
- Convection/radiation loss

Composite
- Orthotropic heat transfer
- Pyrolysis
- Darcy's flow within porous medium
- Thermal expansion

ON-GOING WORK

Relevant fire dynamics
- Large scale (pool) fires
- Soot residues and radiation
- Turbulence and subgrid scale models
- Accurate wall heat flux prediction

Surface couplings
- Heat flux space and time distribution
- Pyrolysis volatiles ignition
- Deformation/Ablation
- Friction due to surface roughness

Volume couplings
- Thermal behaviour
- Mechanical behaviour
- Delamination onset and growth
- Heat and mass transfer within cracked medium

Experimental approach

Experimental and numerical suite

blade

Experimental assessment of anisotropic thermal properties
Laser-induced decomposition of charring materials

fire

Fire-induced decomposition of charring materials
Interaction of pyrolysis volatiles with flame dynamics

inject

Electrical current-induced decomposition of charring materials
Assessment of mechanical properties by fast volume heating

modethec

Multi-species pyrolysis finite volume numerical solver
Heat & mass transfer within anisotropic charring porous materials

adethec

Post-processing toolbox for kinetics and energetics
analysis of decomposing composite materials

ONERA CEDRE

Multi-physics finite volume numerical solver
for energetic multi-phase flow simulations

ONERA ZEBULON

Multi-physics finite element numerical solver
for materials and structures behaviour simulations

Experimental approach

FIRE facility: **F**lame-wall **I**nteraction **R**esearch **E**xperiment

Understanding the fire behaviour of composite materials

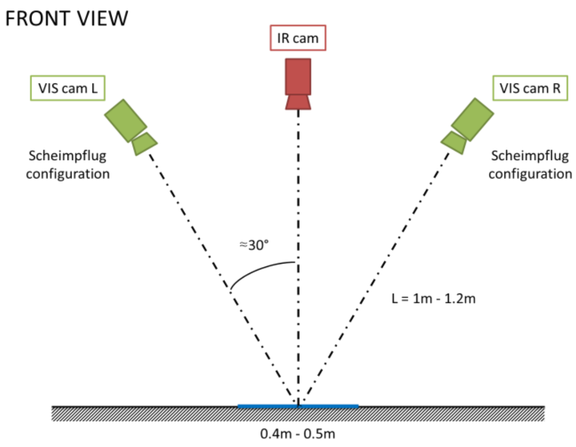
FEATURES

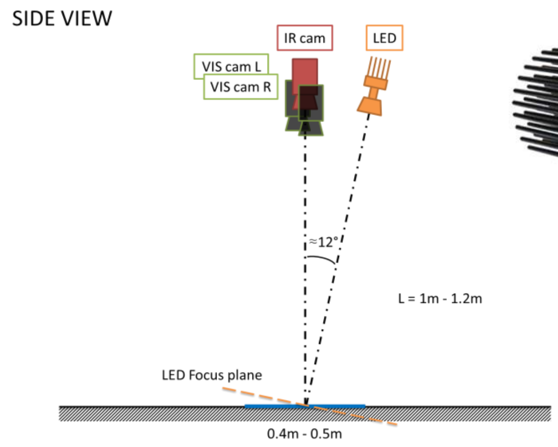
- Test coupon size: 350 x 350mm
- Premixed air-propane burner Ø40mm
- Exposure time: automated moving burner
- Transient temperature maps: **quantitative IR thermography** on the back surface
- Displacement: **DIC** (stereoscopic cameras associated to a high power LED projector)
- **Mass loss**: high precision weighting module
- **Flame dynamics**: Laser Doppler Velocimetry (LDV) and Particle Image Velocimetry (PIV)

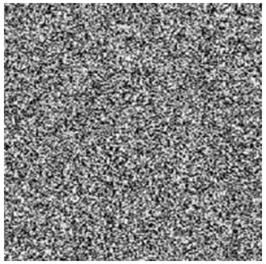
Thermal response during fire-induced decomposition	Interaction between fire and materials	LDV measurement of flame dynamics

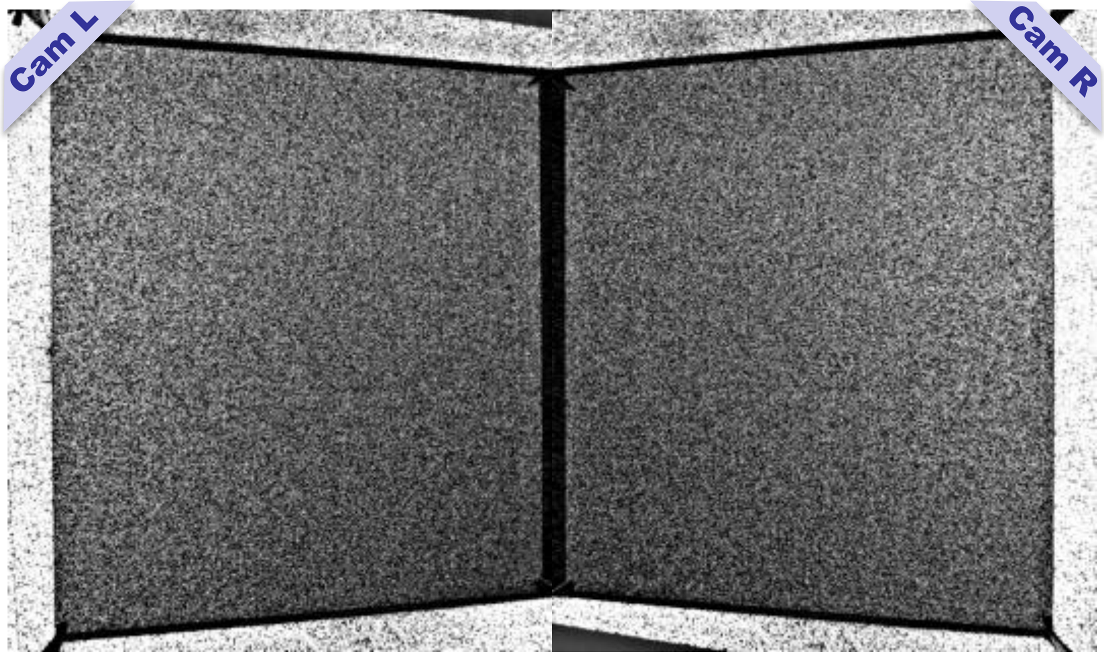
Experimental approach

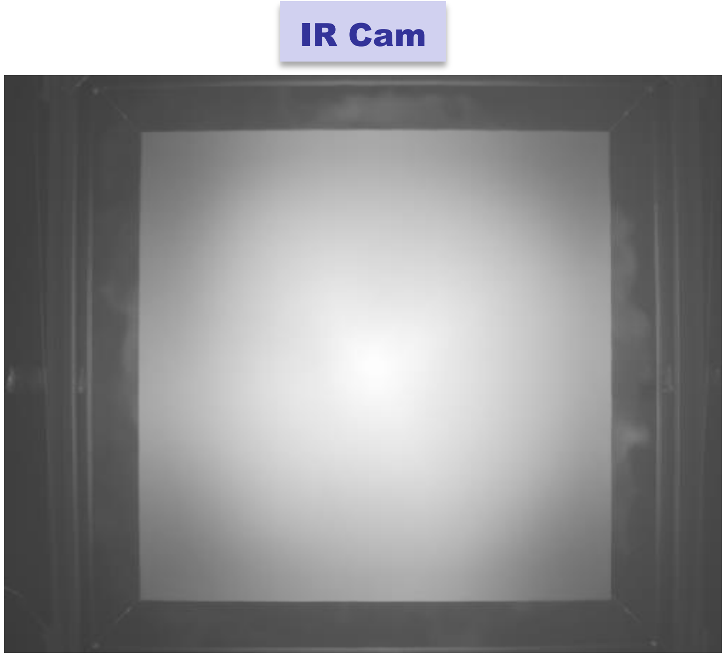
Instrumentation





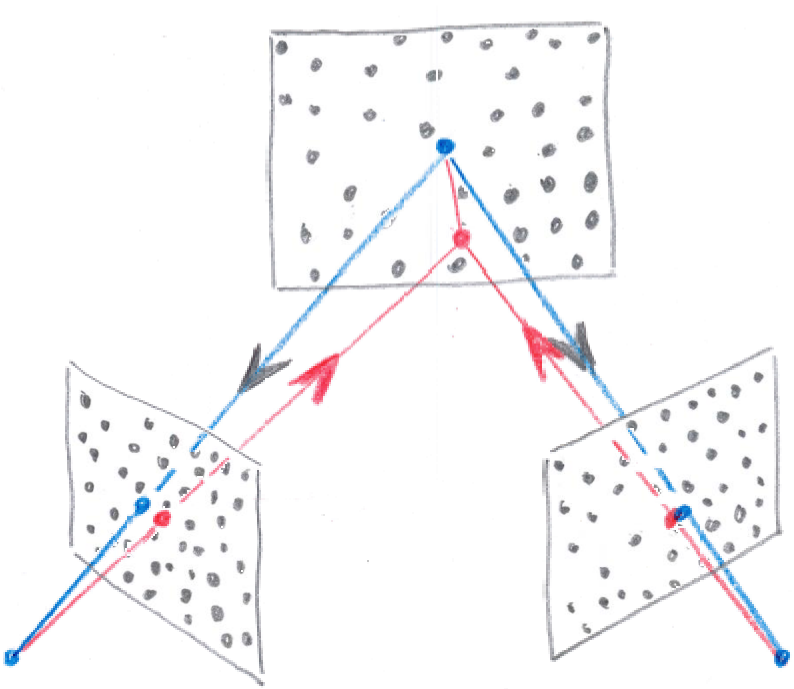
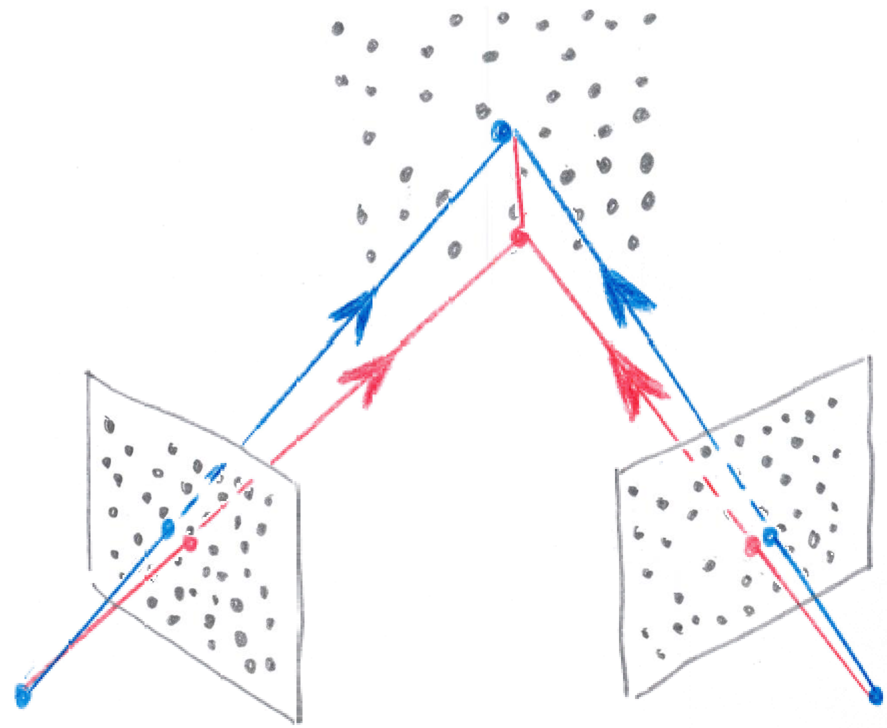






Experimental approach

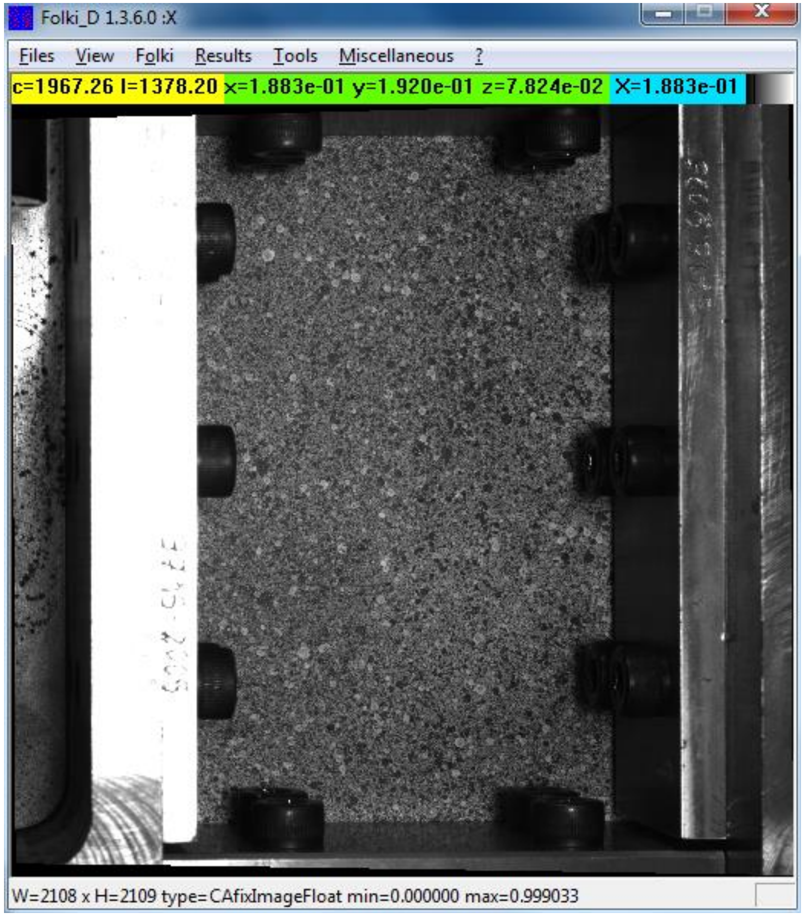
DIC vs. PIV

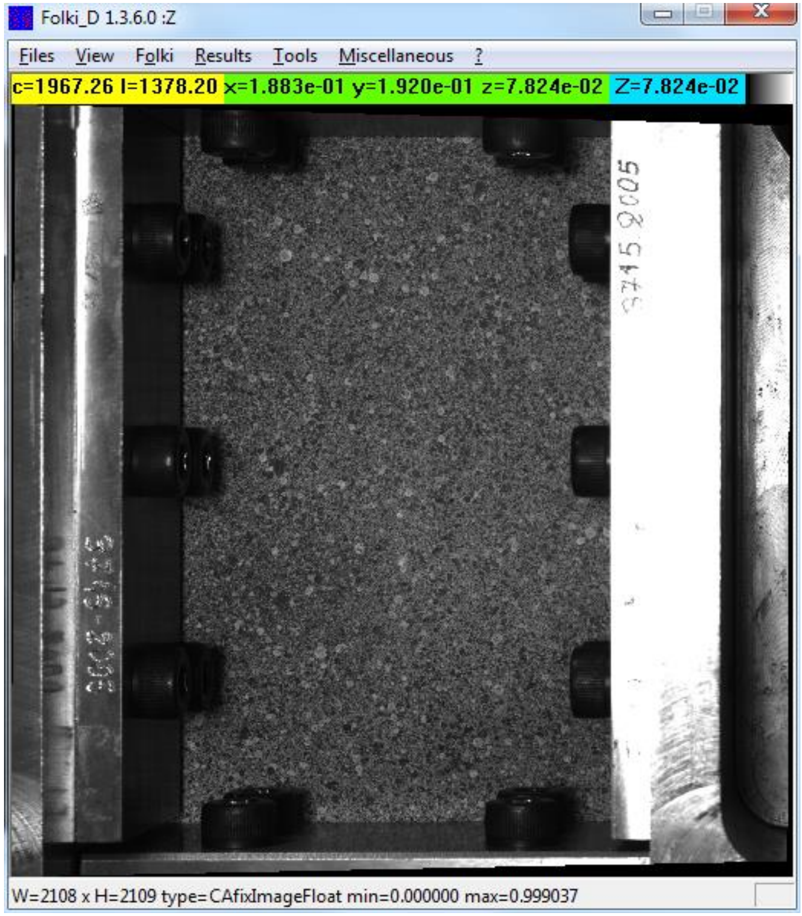
PIV *Particle Image Velocimetry*	**DIC** *Digital Image Correlation*
	
projected in the image, 2x2D motion finds 3D point Initial shape: **plane** Final shape: **deformed plane (3D)**	Initial correlation finds 3D point 2x2D motion finds 3D point Initial shape: **3D shape** Final shape: **deformed 3D shape**

Experimental approach

A brief overview of FOLKI_D

Initial shape





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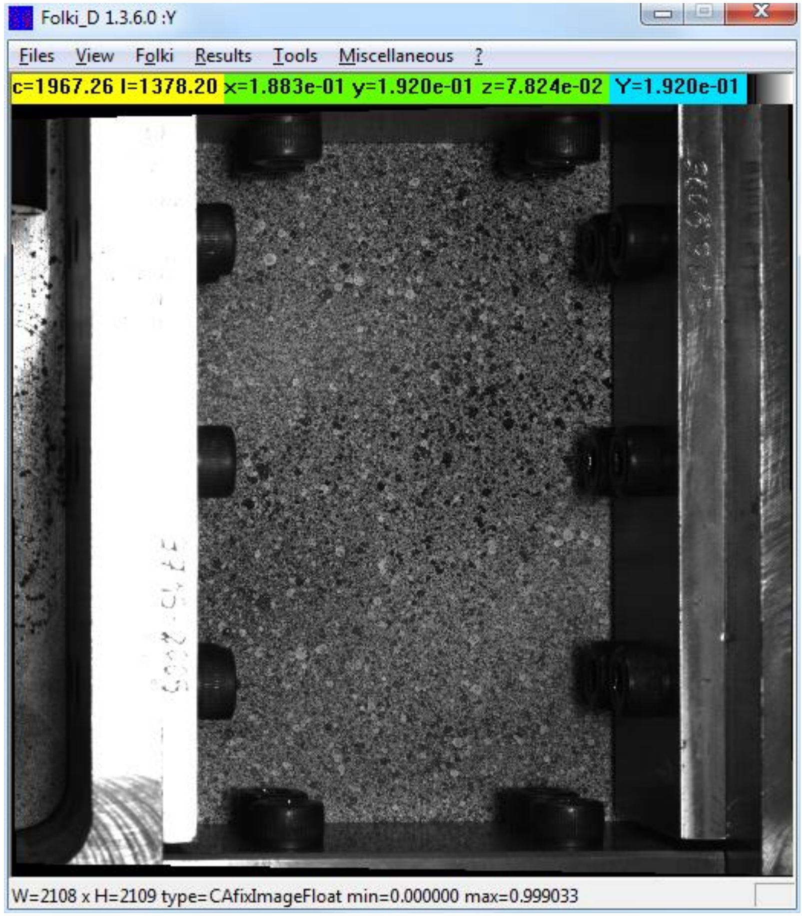
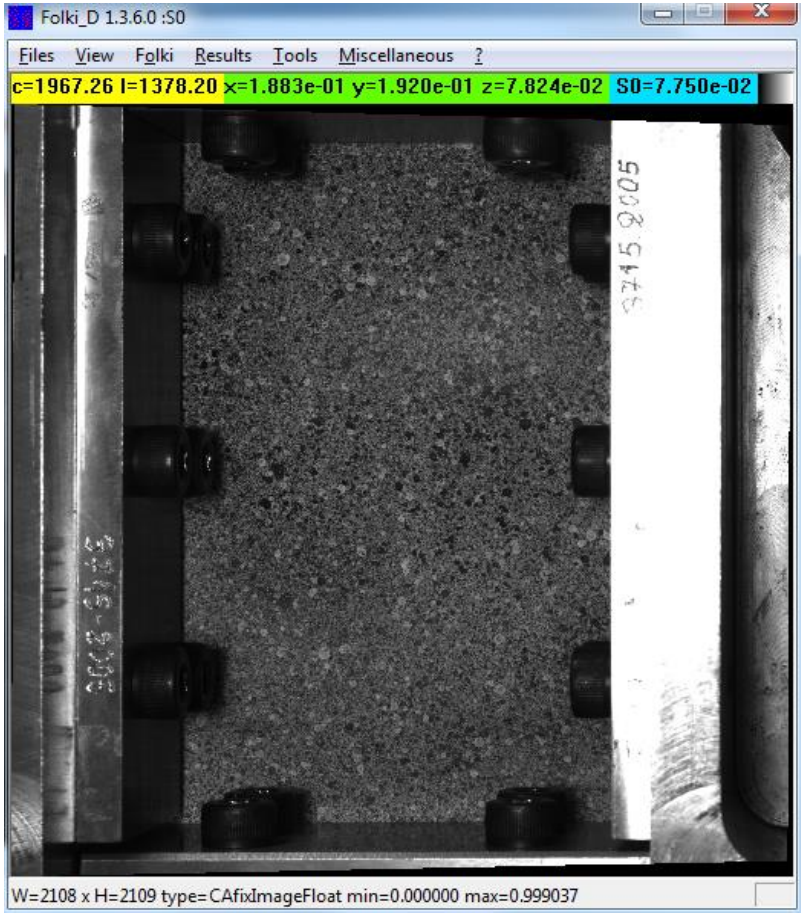
Experimental approach

A brief overview of FOLKI_D

Final shape





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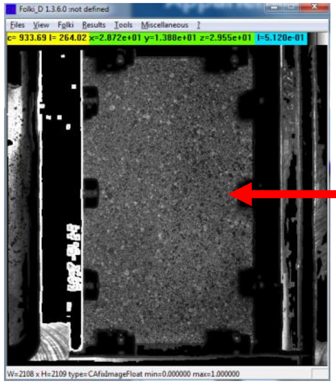
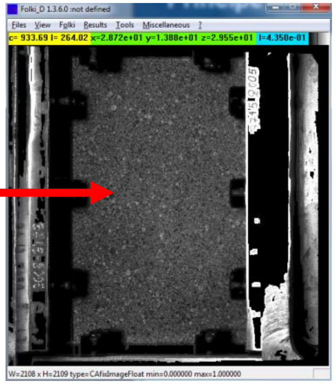
Principle

FOLKI 1C field:

stereovision for the final shape





Minimizing

$$\sum_{m \in W(k)} \left(I_1(m) - I_2(m + u(k))\right)^2$$

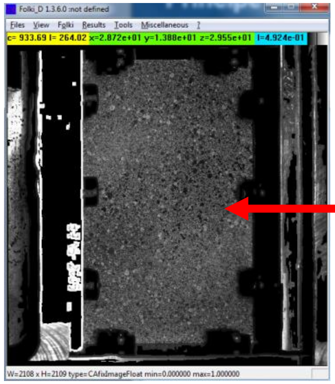
Iterative process

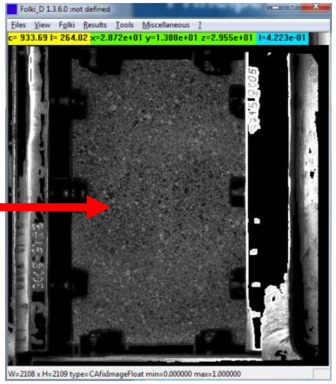
$$\sum_{m \in W(k)} \left(I_1(m) - I_2(m + u(m) + \quad du(k))\right)^2$$

FOLKI 2C field: displacement

FOLKI 1C field:

stereovision for the initial shape





Experimental approach

Camera calibration

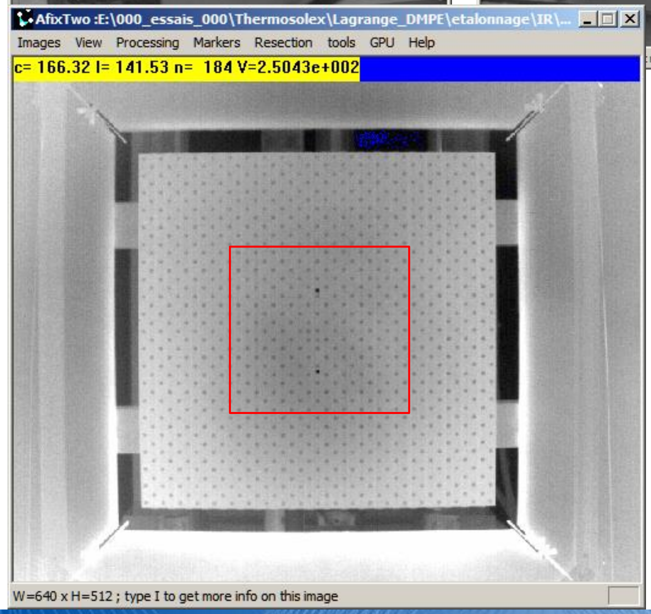
DIC:

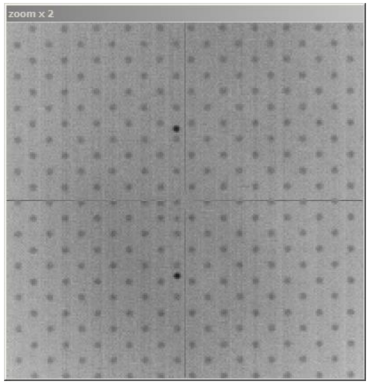
usual CB

pattern coding

IR:

may use same DIC CB





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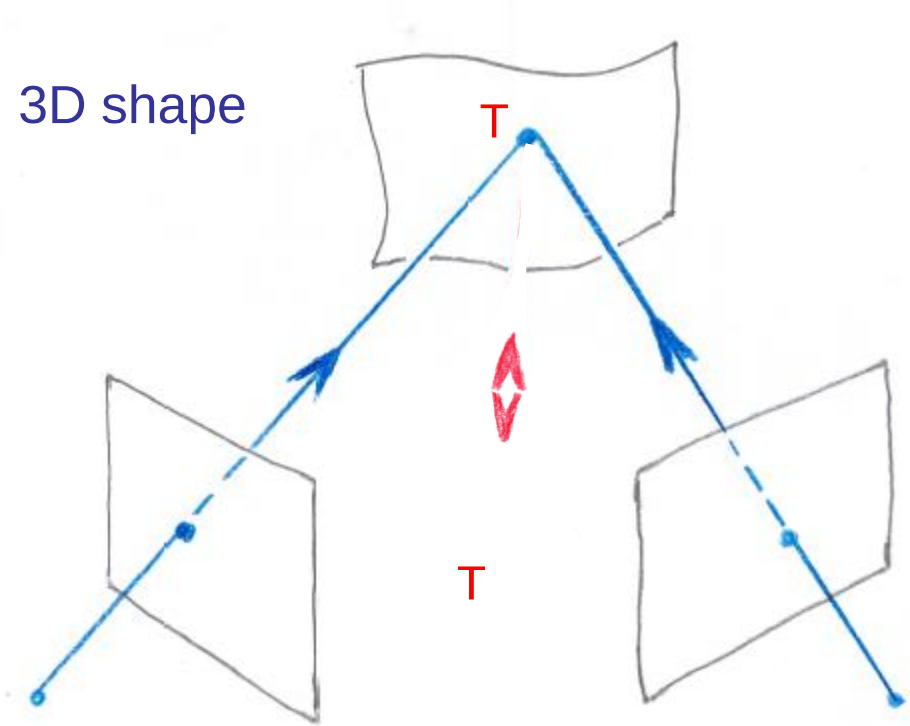
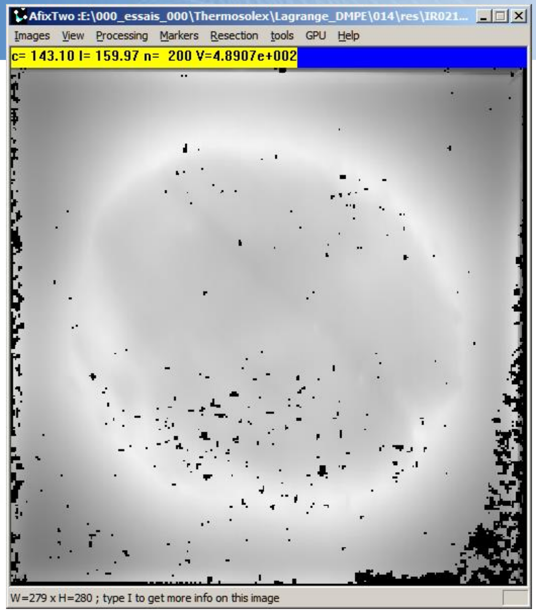
Experimental approach

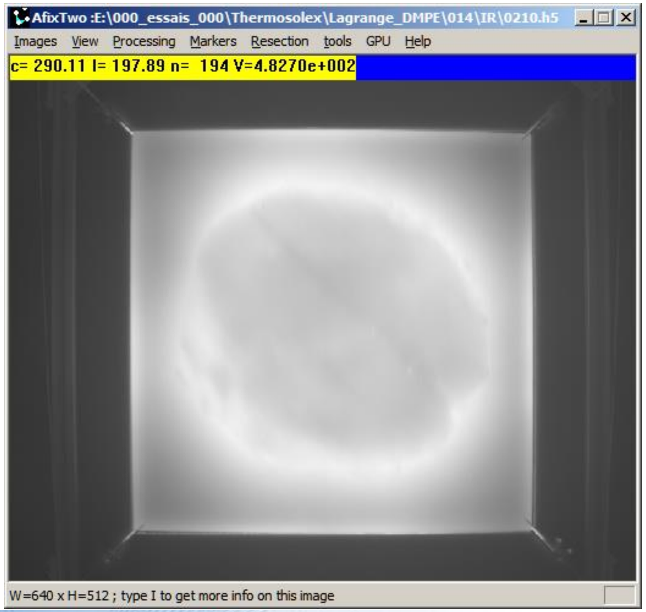
Lagrangian tracking in IR images

DIC : 3D shape



IR image





Development within THERMOSOLEX
(ONERA project)

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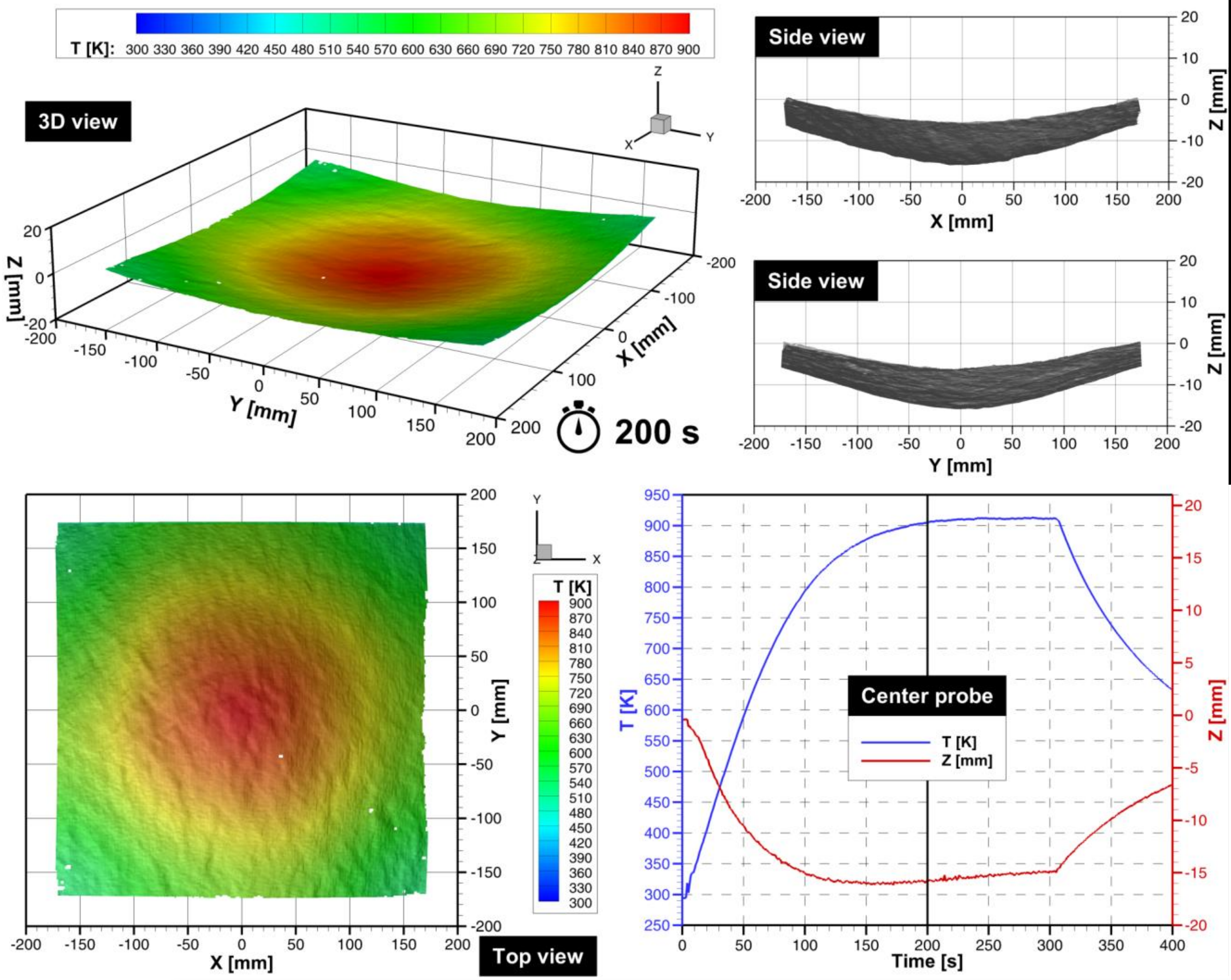
Metallic panel (3mm-thick INCO600)



Back surface thermal response and 3D full-field displacement associated photographs on the exposed side

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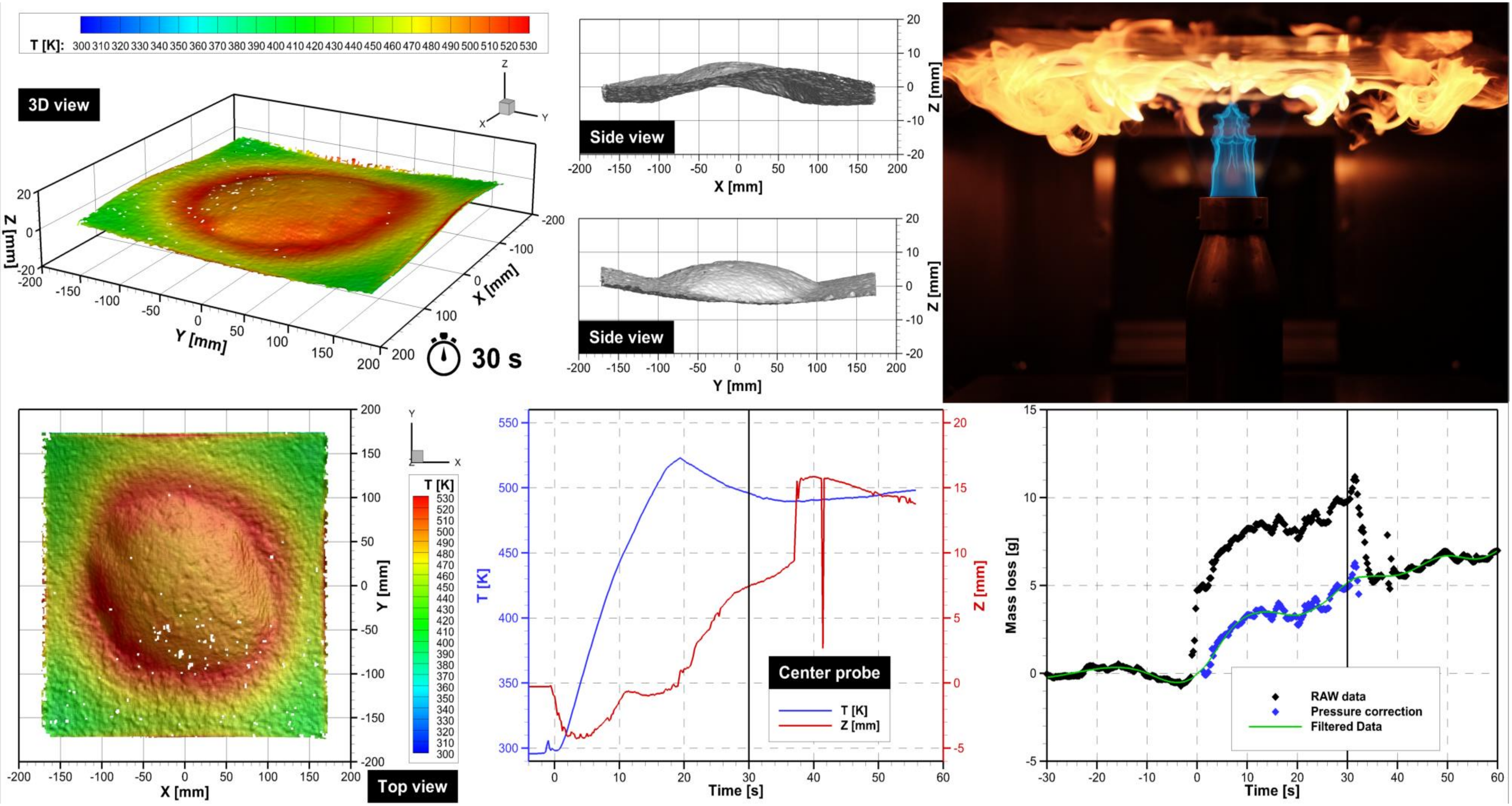
Composite laminate (8-ply T700GC/M21)



Back surface thermal response and 3D full-field displacement associated with mass loss and photographs on the exposed side

Results

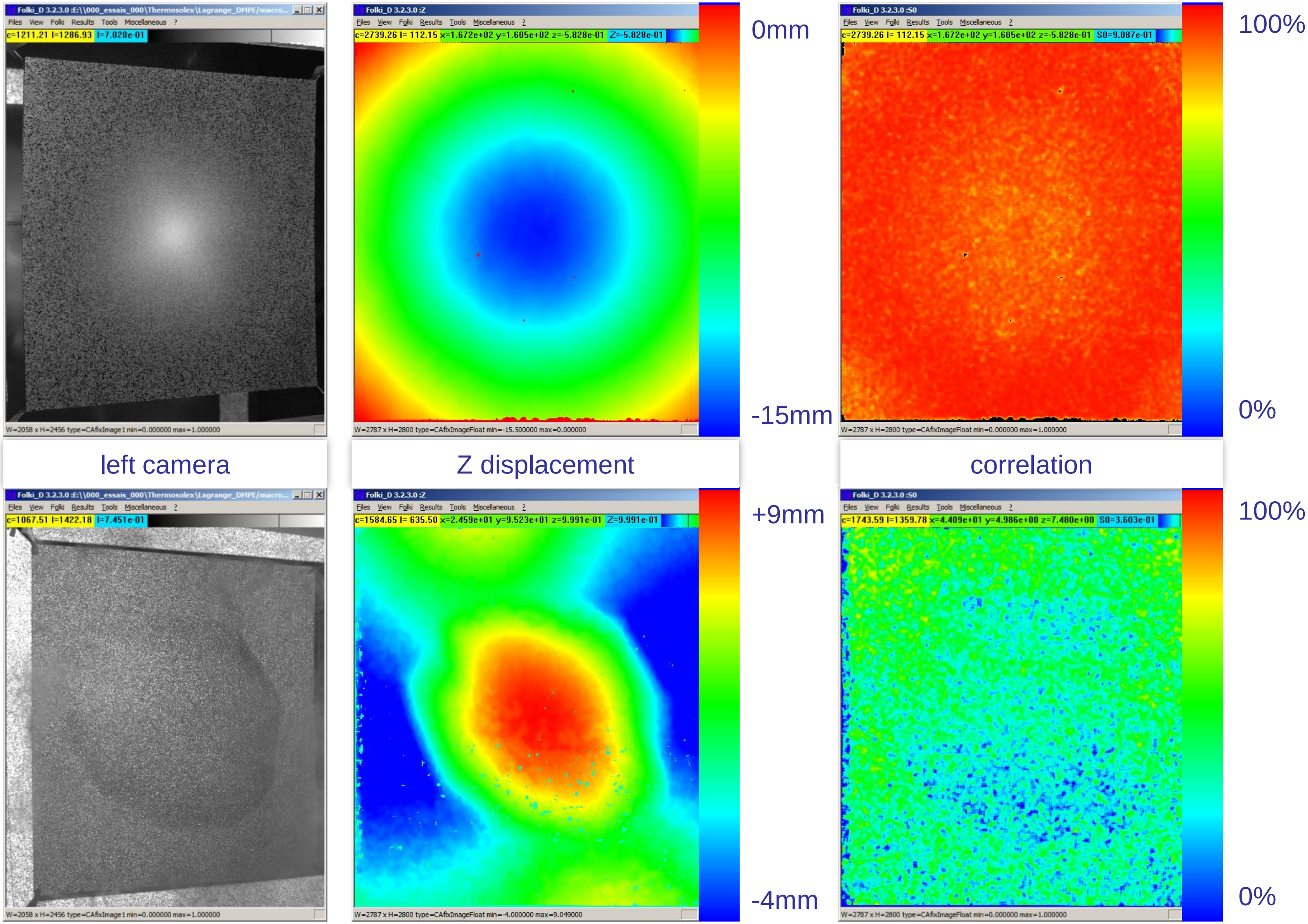
Thermal effects on correlation

INCO600

Surface radiation
Thermal plume
Refractive index variations

Composite

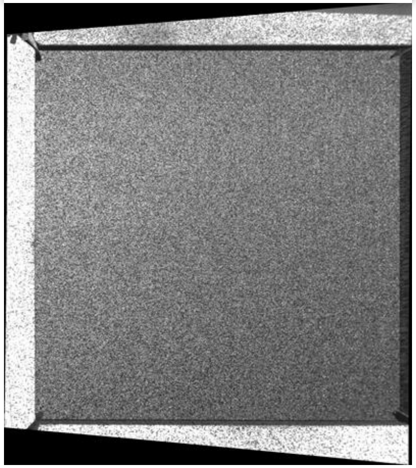
Pyrolysis
Delamination
Off-gassing

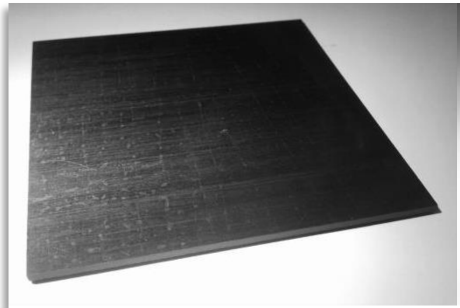


Conclusions

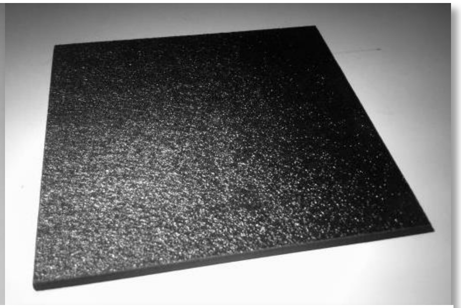
- Lagrangian tracking implemented
- Valuable results even with pyrolysis
- **On-going and forthcoming improvements:**
  - *Using a natural texture for composite ?*
  - *High(er) illumination energy (LED) to increase the correlation*
  - *Angular emissivity correction*
  - *Thermal effects correction*
  - *Application on the exposed surface*
    - Training period and PhD thesis proposed in 2019 !

Rectified left DIC images





Smooth surface



Rough surface

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fire
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physics of fire