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How to protect aircraft against fire with an intumescent cake?

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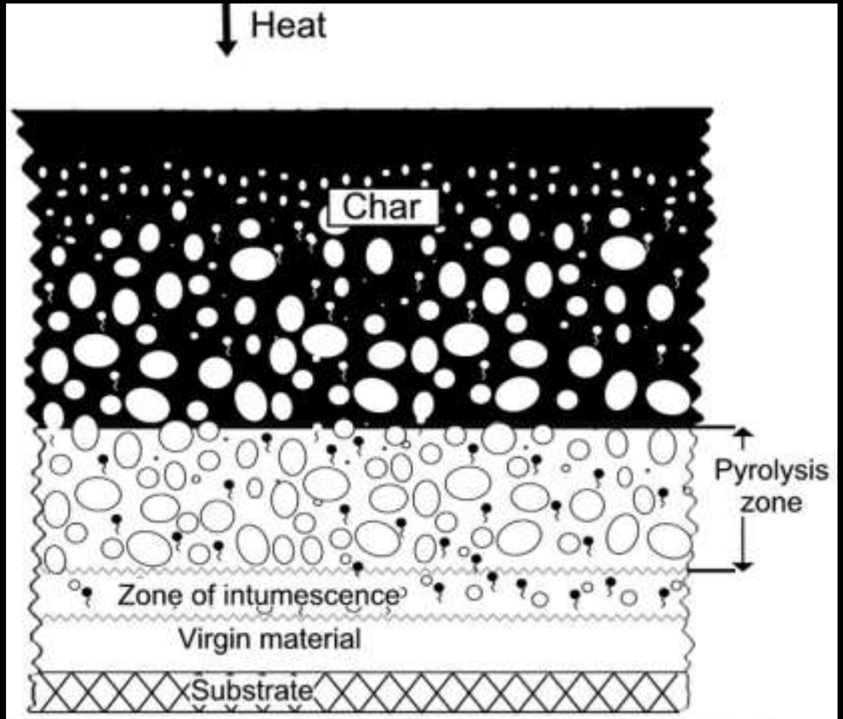
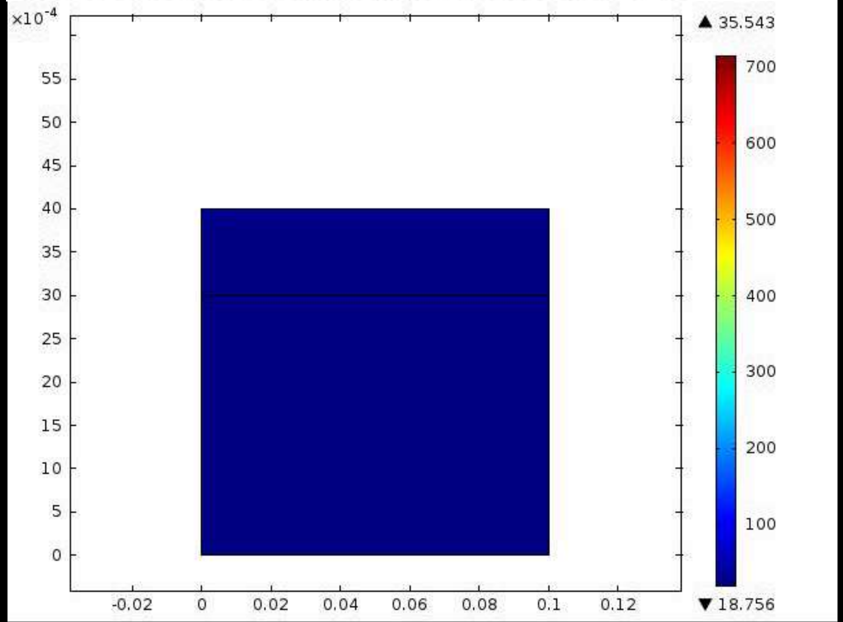
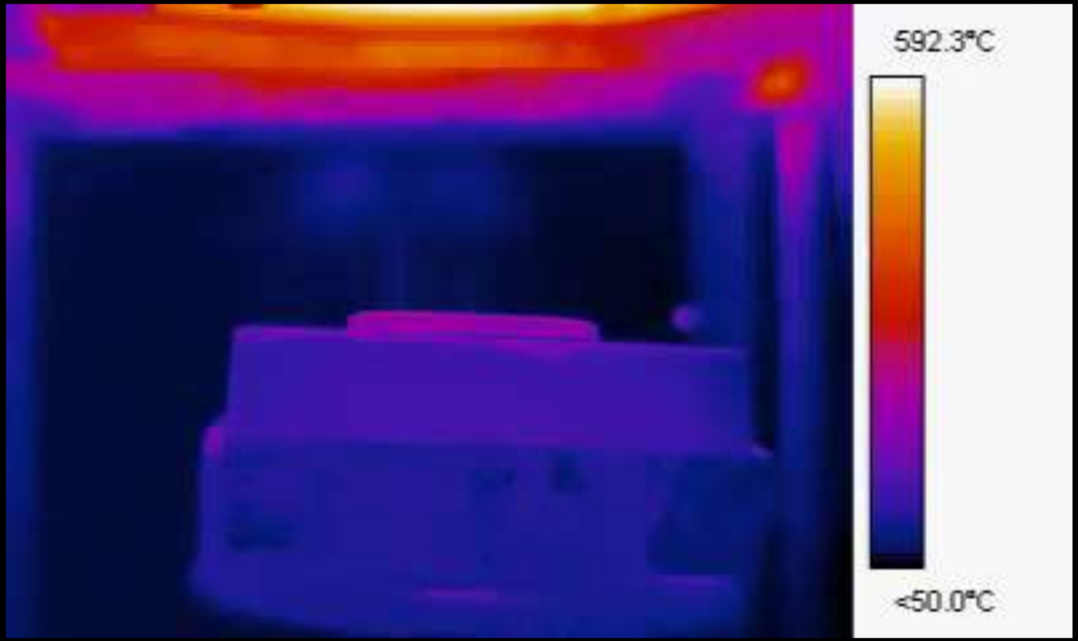
Intumescence?





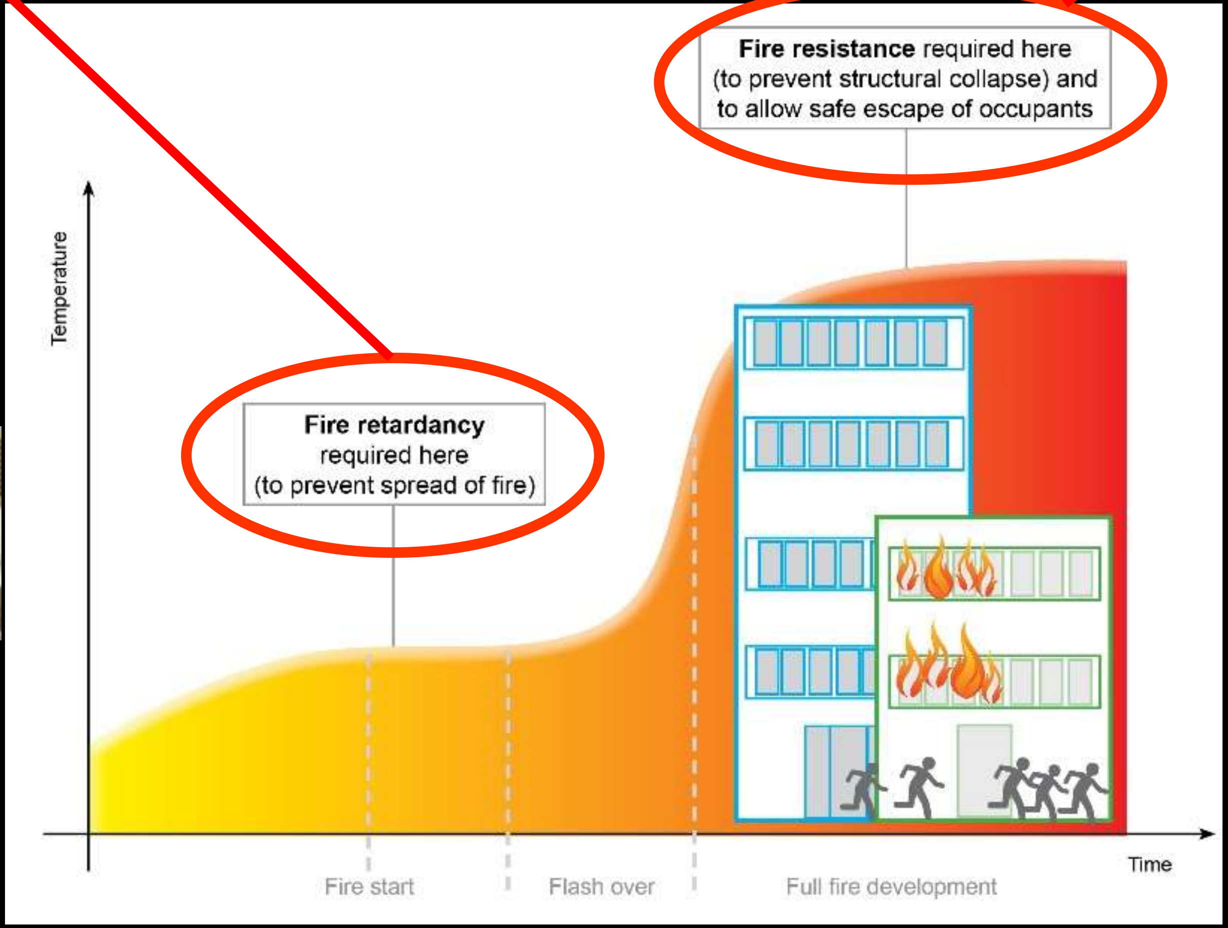
Expanding char forming heat and mass barrier



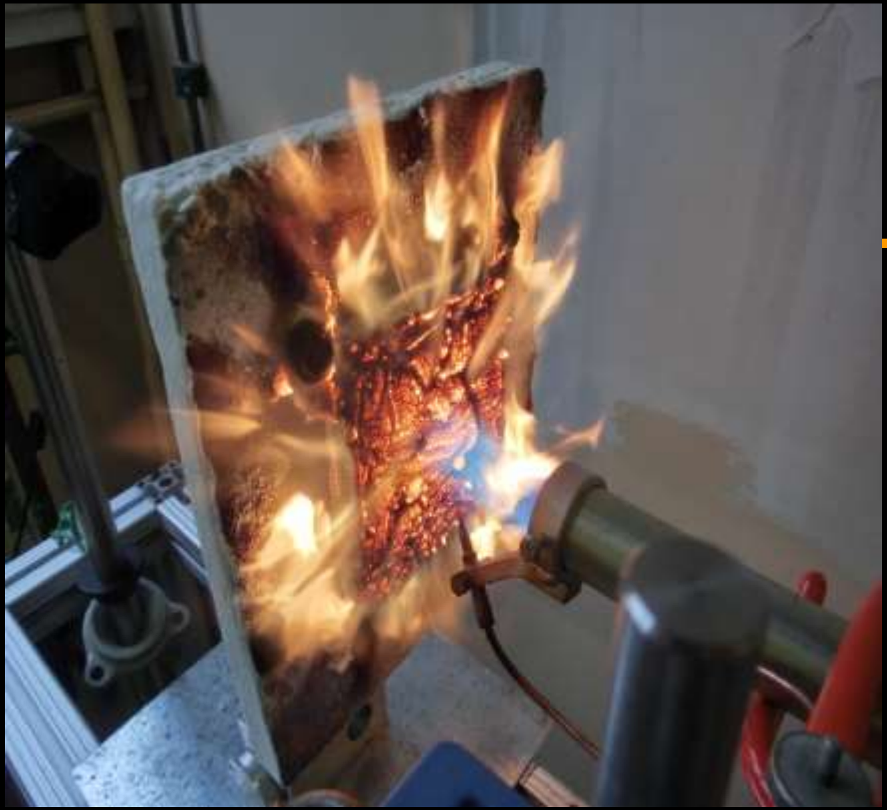
Intumescence for reaction and resistance to fire

- **Applications: E&E, railway, cable & wire, aircraft cabin …**
- **Fire scenarios (testing): UL94, glow wire, cone calorimeter, SBI, EN 50399 …**

- **Applications: building, offshore platform, aircraft …**
- **Fire scenarios: UL1709, ISO834, ISO2685, jetfire …**



Fire protection of CFRP



Fire protection of composite: testing?

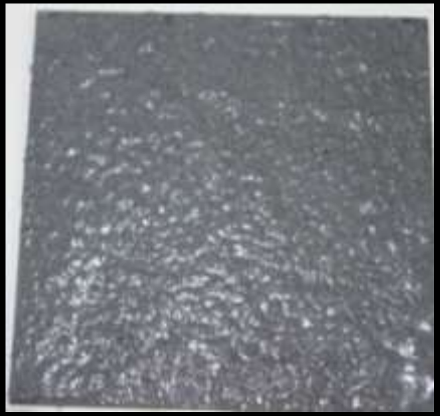
Fire resistance of fuselage and other parts of aircraft: **full scale test or burnthrough test (jet fuel fire at ~186 kW/m²)**

- Time consuming
- Expensive
- Slow development

Post-crash fire simulation in full scale indoor at FAA

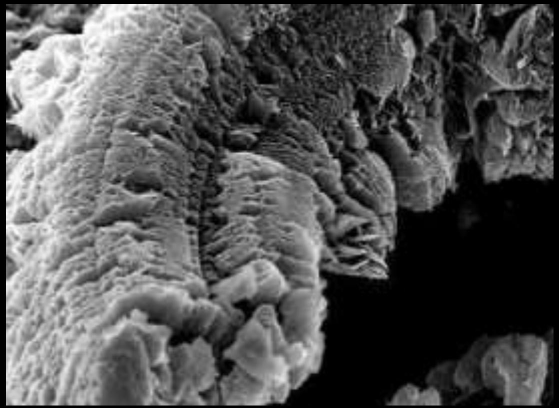
Burnthrough test (NexGen)

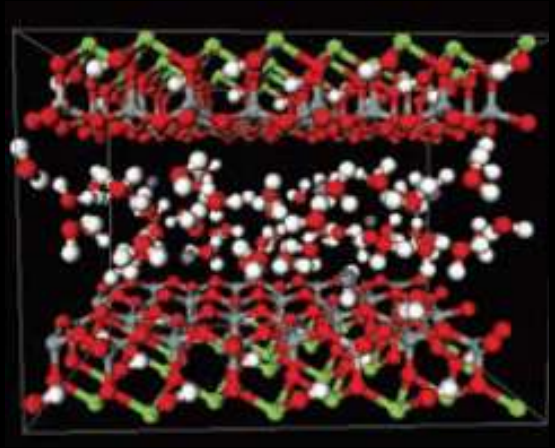
Silicone-based intumescent coating



Intumescent paint on CFRP: silicone-based coating containing expandable graphite* compared to low intumescing paint

Silicone formulation	F1 – High intumescing coating*	F2- Low intumescing coating
Silicone matrix	56%	56%
Expandable graphite	25%	-
Calcium carbonate	12%	37%
Clay	7%	7%

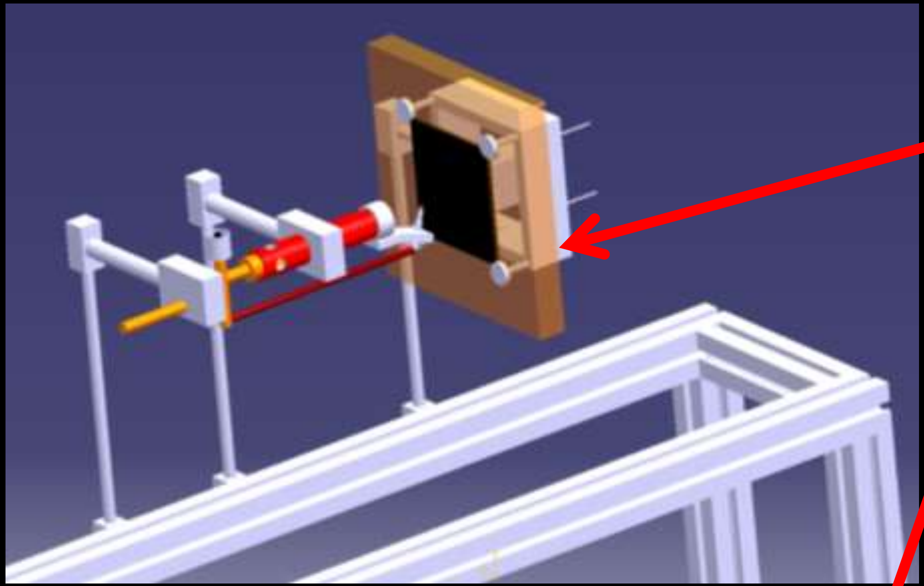




S. Bourbigot et al. "Protecting substrates against damages by fire", WO 2013/150121 - Dow Corning, 2013

Small scale test: Experimental set up

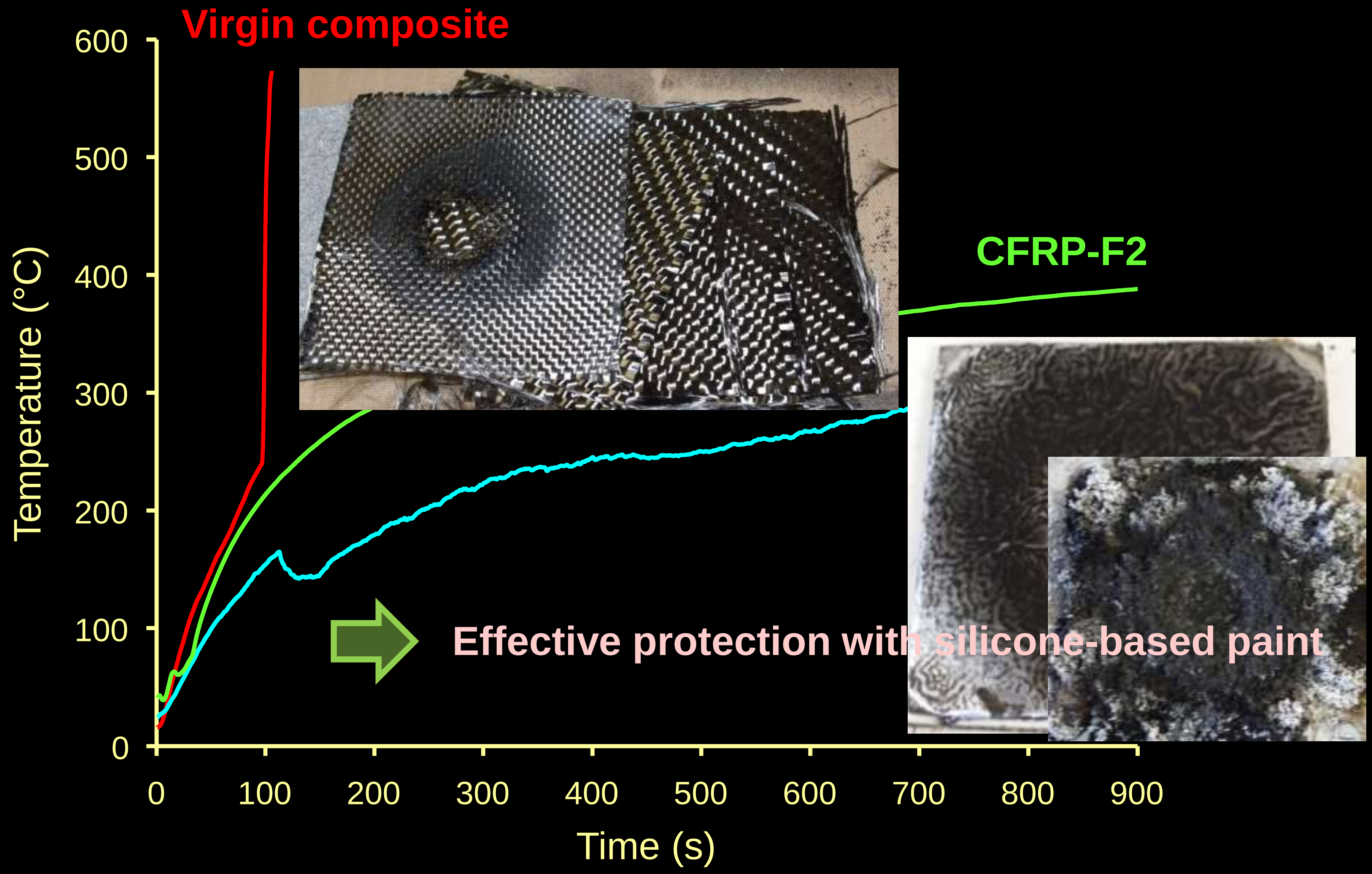
Infrared pyrometer and Th. stuck on composite (*T* = *f*(*t*))



Sample + holder (*insulative ceramic*)

Burner (*200 kW/m² at the surface – T_{flame} ~ 1100°C*)

Protection by intumescence: 1000µm

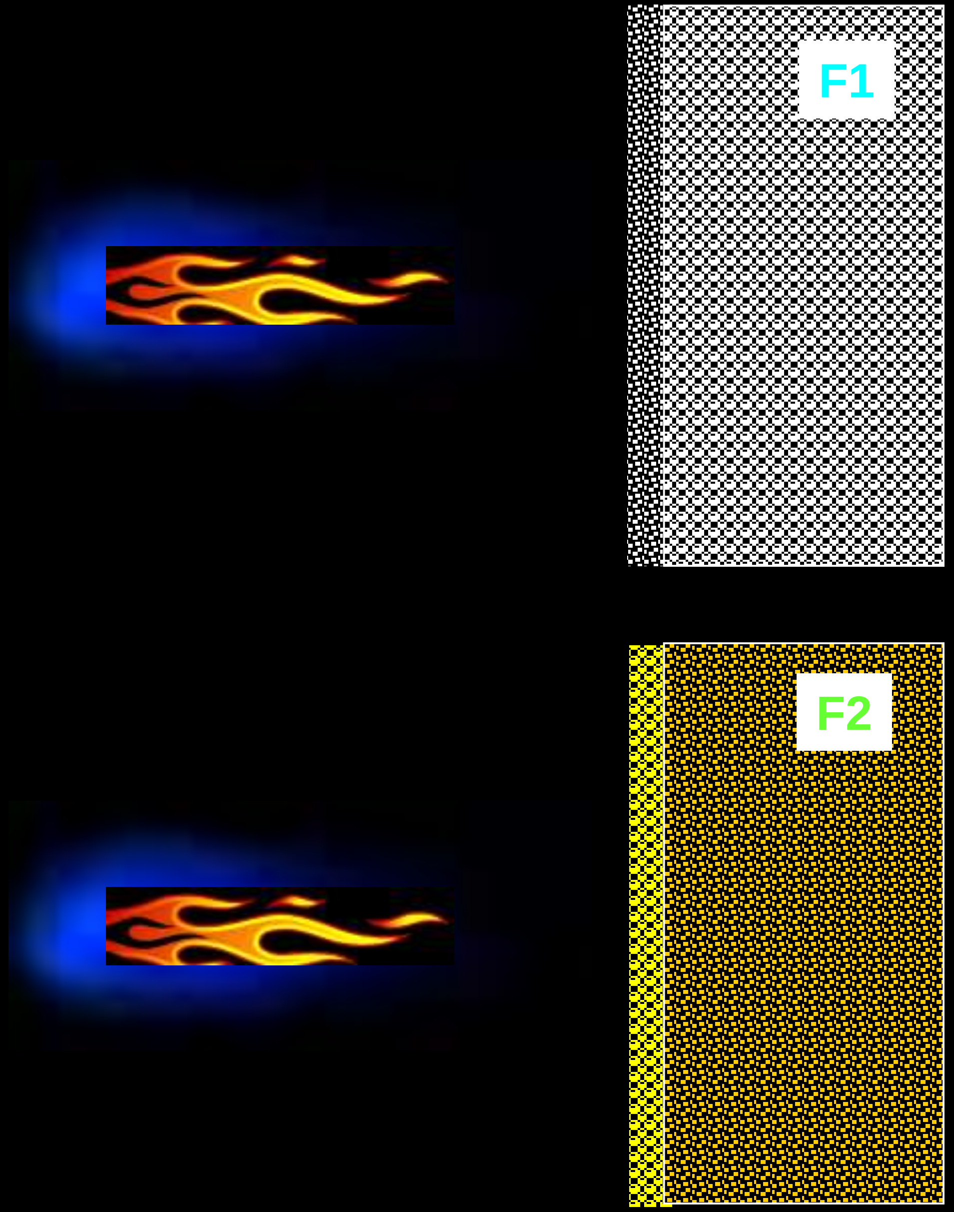


Protection by intumescence

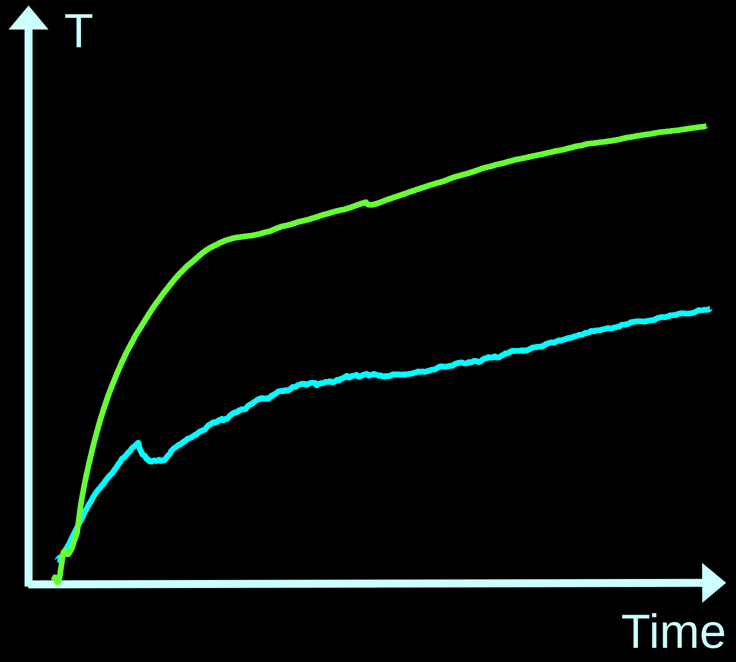
Virgin composite

CFRP-F1

Mechanism of protection



- Heat barrier: high expansion, low k (0.4 W/m.K@600°C)
- Structure: high cohesion thanks to chemical interactions (SiC, Ca-Si)



- Heat barrier: low expansion, low k (0.4 W/m.K@600°C)
- Structure: cohesive porous structure (highly polymerized Si, Ca-Si)

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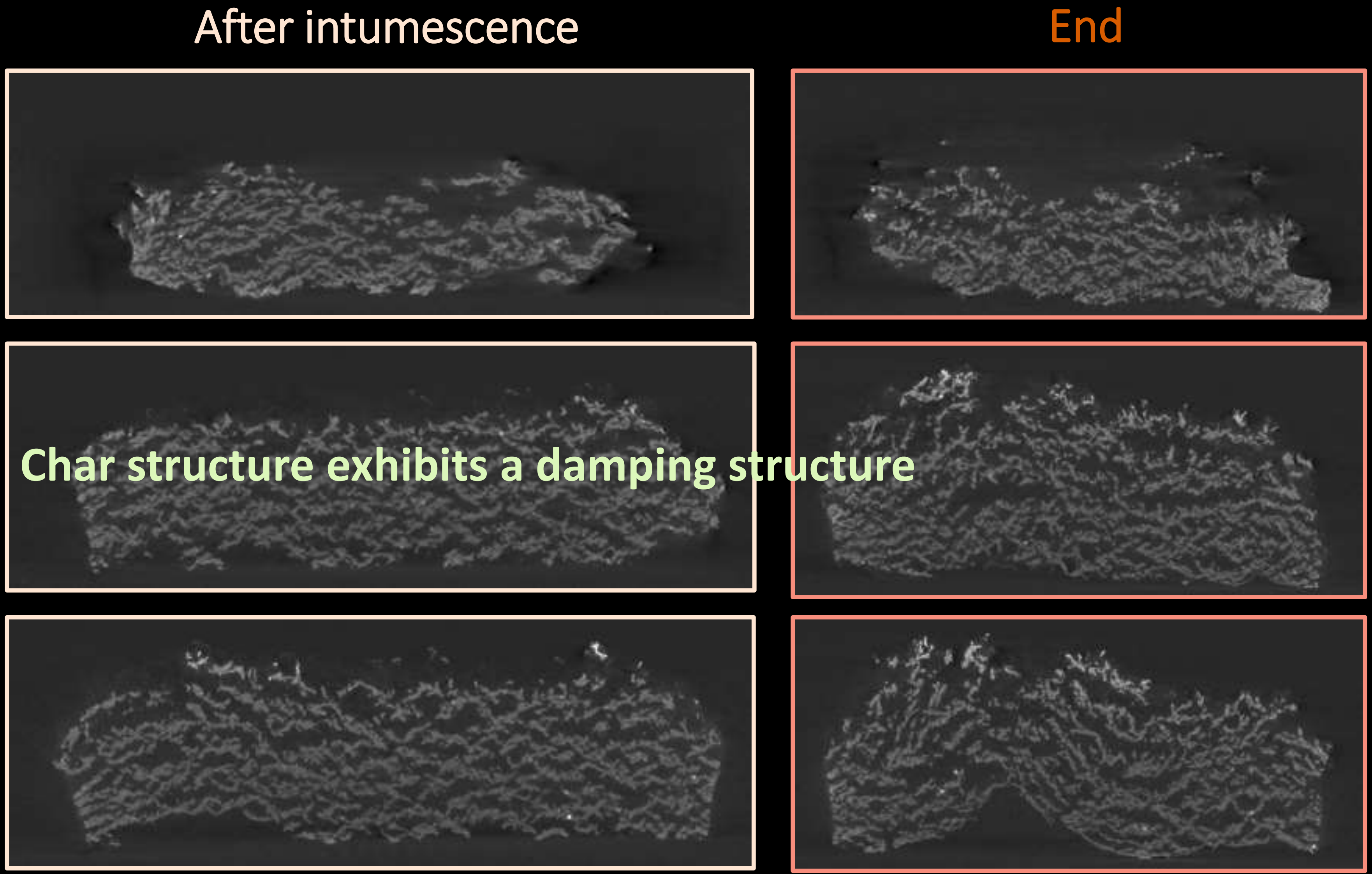
Char characterization: X-ray tomography

Internal intumescent structure : slices at different z of char residues after test



Char structure exhibits a damping structure

Char characterization: fractal dimension

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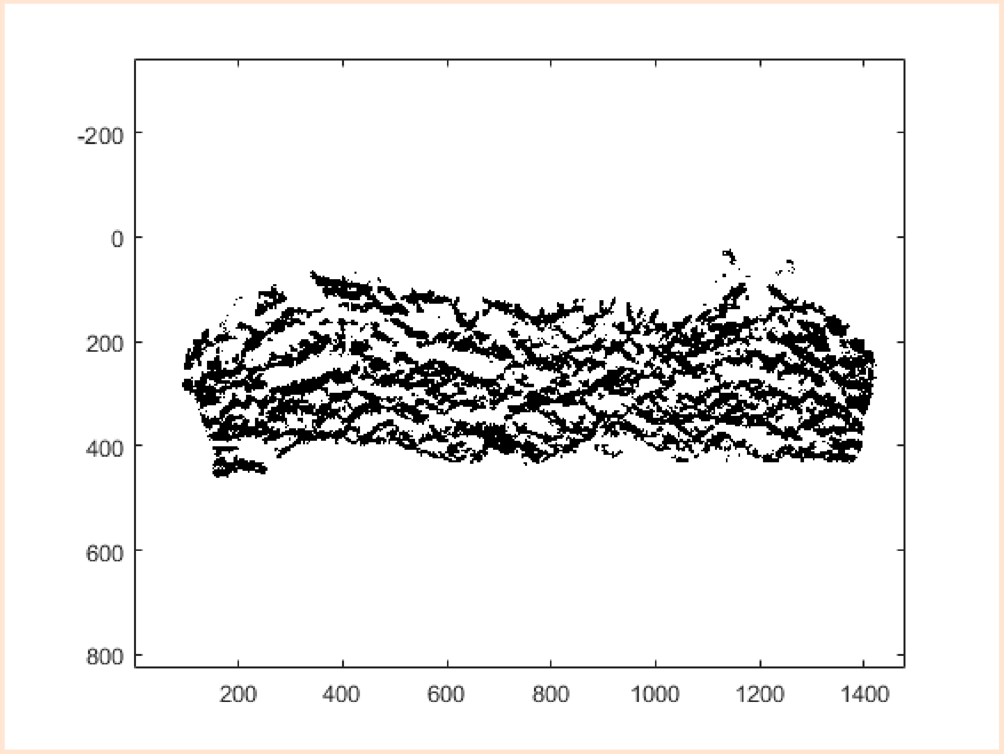
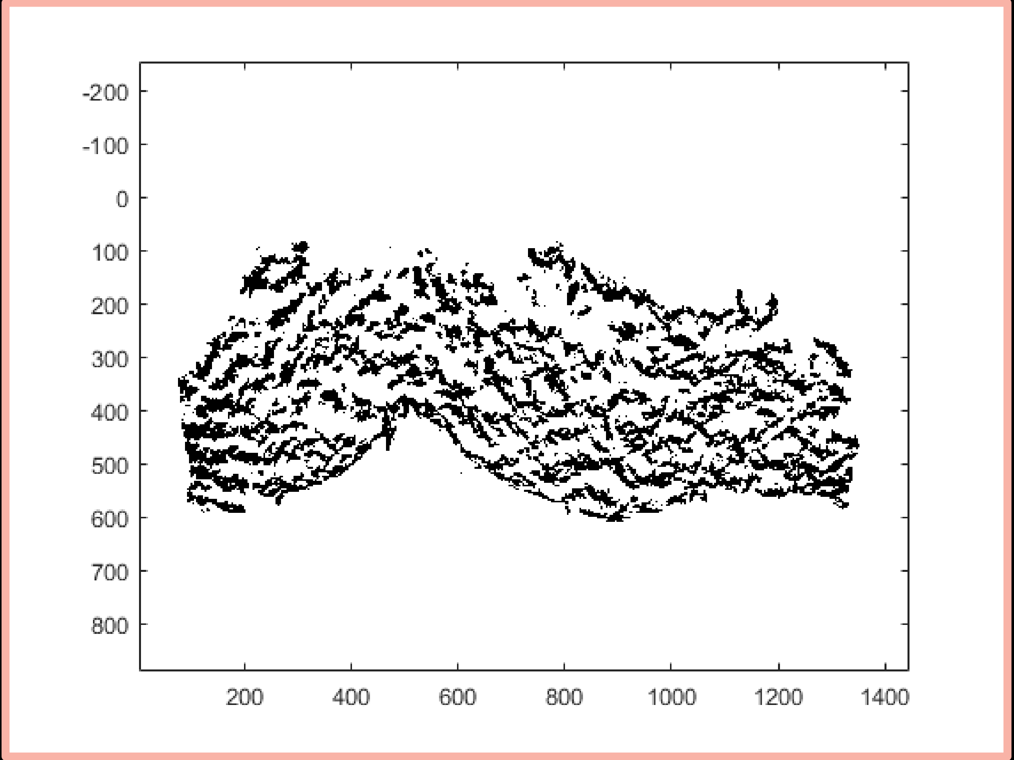
Binarization: extraction of the fractal dimension on a determined scale

After intumescence



Df = 1.7 on 100-2000 µm

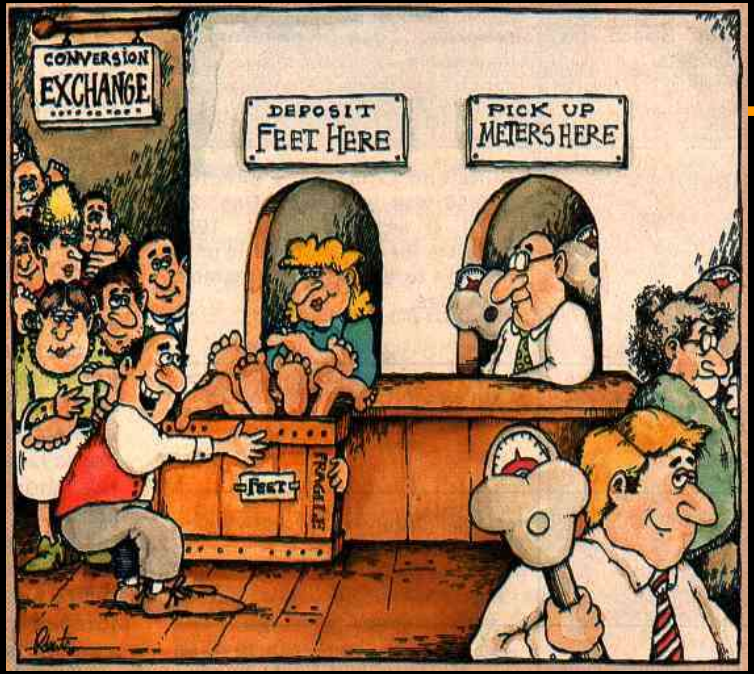
End



Df = 1.7 on 100-700 µm

Df suggests an oriented materials (higher aspect ratio): correlation with char strength?

ISO 2685 at reduced scale: dimensional analysis



Fire scenario at the small scale: how to play?

Lezard as big as a house?!

Linear extrapolation: feeling of visuals!

Toward scale reduction?

ISO 2685: goal and test

Pass/fail test for equipment located in fire zone (engine, auxiliary unit):

- Heat flux of 116 kW/m²
- T_{flame} of 1100°C
- Withstanding of the component for 5 min ⇨ fire proof
- Withstanding of the component for 15 min ⇨ fire resistant

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ISO 2685: modeling and analysis

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$$\begin{cases} \rho C\dot{\bar{T}} - k\Delta\bar{T} = \dfrac{q_{av} - q_{ar}}{e_p} \\ q_{ar} = h_{ar}(T - T_{amb}) + \varepsilon\sigma(T^4 - T_{amb}^4) \\ q_{av} = h_{av}(x,y)(T_g - T) + C(x,y)\sigma(T_f^4 - T^4) - \varepsilon\sigma(T^4 - T_{amb}^4) \end{cases}$$

Dimensionless numbers are determined:

τ : duration of the experiment
L: length of the plate

$$\tilde{x} = x/L \quad \tilde{y} = y/L \quad \tilde{t} = t/\tau \quad \tilde{T} = T/T_{amb}$$

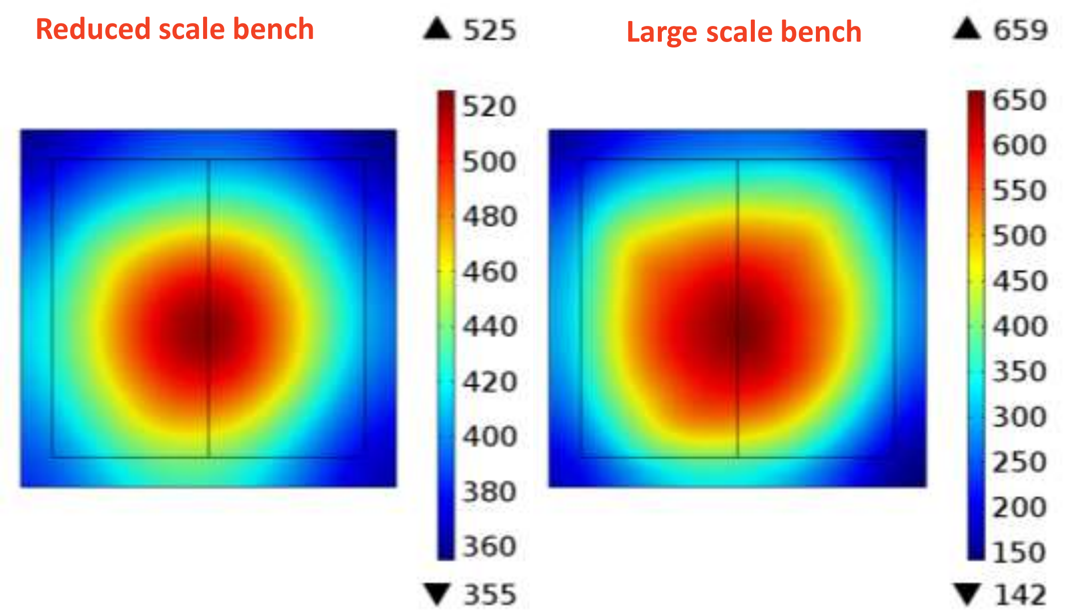
$$\frac{\tau_{ep}}{\tau}\frac{\partial\tilde{T}}{\partial\tilde{t}} - \left(\frac{e_p}{L}\right)^2\Delta\tilde{T} = B_i^{av}\left(\frac{T_g}{T_{amb}} - \tilde{T}\right) + CN_r\left(\left(\frac{T_f}{T_{amb}}\right)^4 - \tilde{T}^4\right) - 2\varepsilon N_r(\tilde{T}^4 - 1) - B_i^{ar}(\tilde{T} - 1)$$

$$B_i^{av} = \frac{e_p h_{av}}{k} \qquad B_i^{ar} = \frac{e_p h_{ar}}{k}$$

Biot numbers linked to the convection on the 2 faces

$$F_O^{ep} = \tau/\tau_{ep} \qquad \tau_{ep} = \frac{\rho C_p e_p^2}{k} \qquad N_r = \frac{e_p \sigma T_{amb}^3}{k}$$

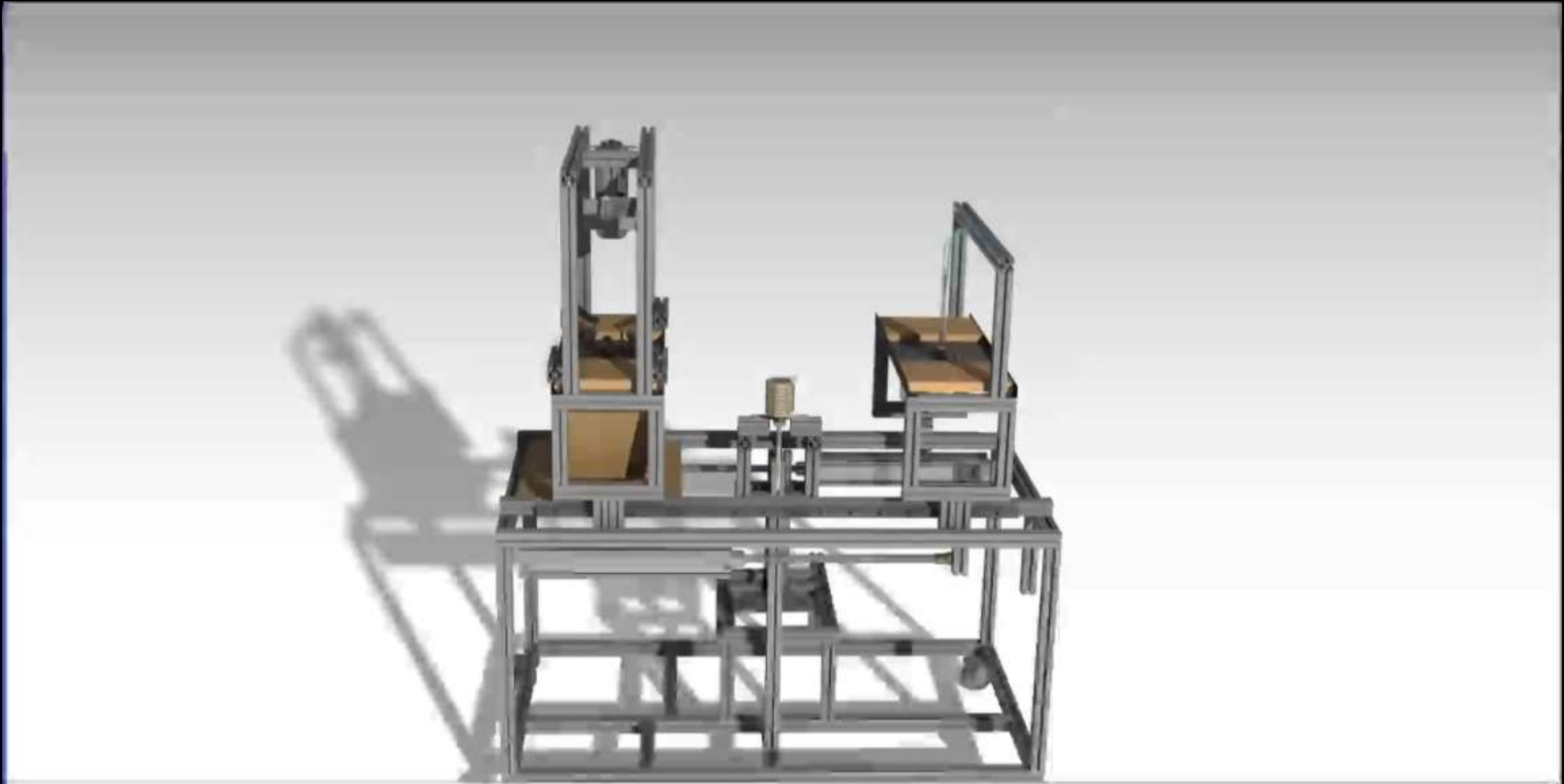
Fourier, time and radiative numbers



Lower temperature field for the small- scale bench

No linear extrapolation but dimensional analysis to understand the differences

Small scale test: Experimental set up

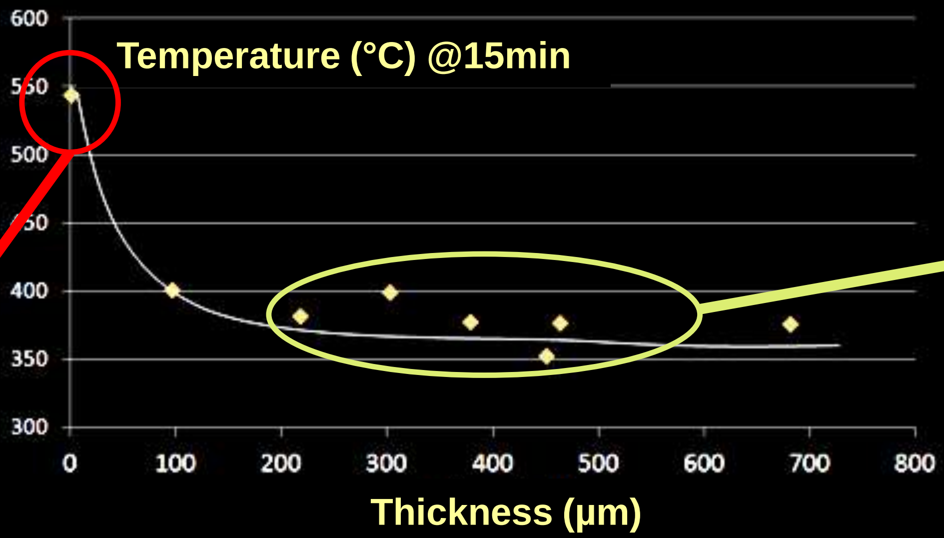


Safran Project:

Design and improvement of a test bench to fire a reduced scale

Small scale test: intumescent CFRP

Evaluation of intumescent CFRP



Efficiency of the fire protection from 250 µm via an intumescent behavior

Summary and future work

- **Similitude:** ***scale reduction is not straight forward but correlation can be found (ISO2685, NexGen…)***

- **Intumescence:** ***appropriate way for reaction and resistance to fire***

- **Further models:** ***development of model working in flaming conditions (in progress)***

- **Gas phase:** ***full characterization of the gas phase taking into account soot (radiative properties)***

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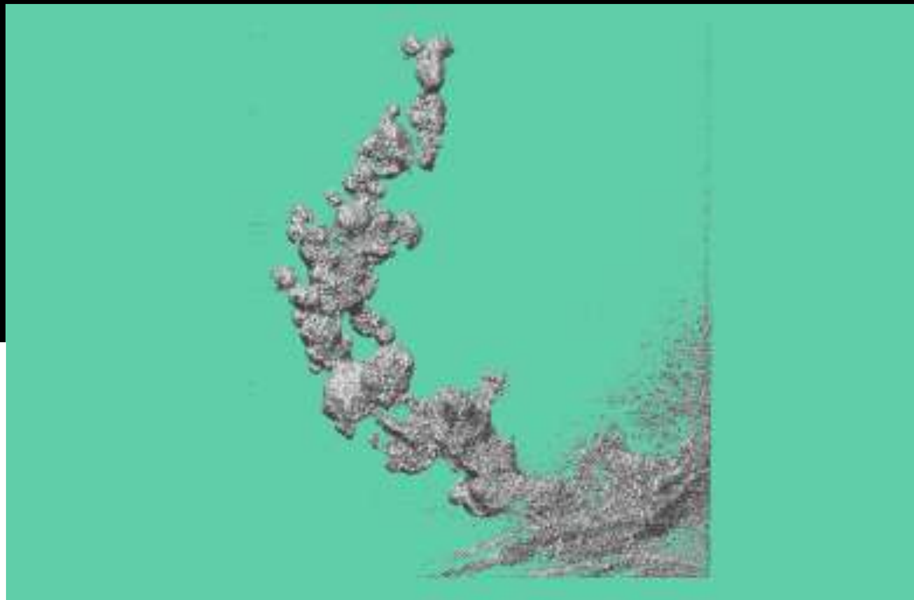

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Acknowledgment









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ERC AdG: FireBar-Concept


FireBar Concept