Composites at Lake Louise (CALL 2015) Proceedings

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Composites on fire at reduced scale: evaluation, characterization and modeling

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COMPOSITES ON FIRE AT REDUCED SCALE: EVALUATION, CHARACTERIZATION AND MODELING

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ÉCOLE NATIONALE SUPÉRIEURE DE CHIMIE

Fire protection of composite: why?

CFRP in aircraft structure has introduced potential fire threats

- **engine compartments (fuel leakage can occur)**
- **fuselage (post-crash fire)**

Jet fuel fire: heat flux between 110 and 200 kW/m²

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)

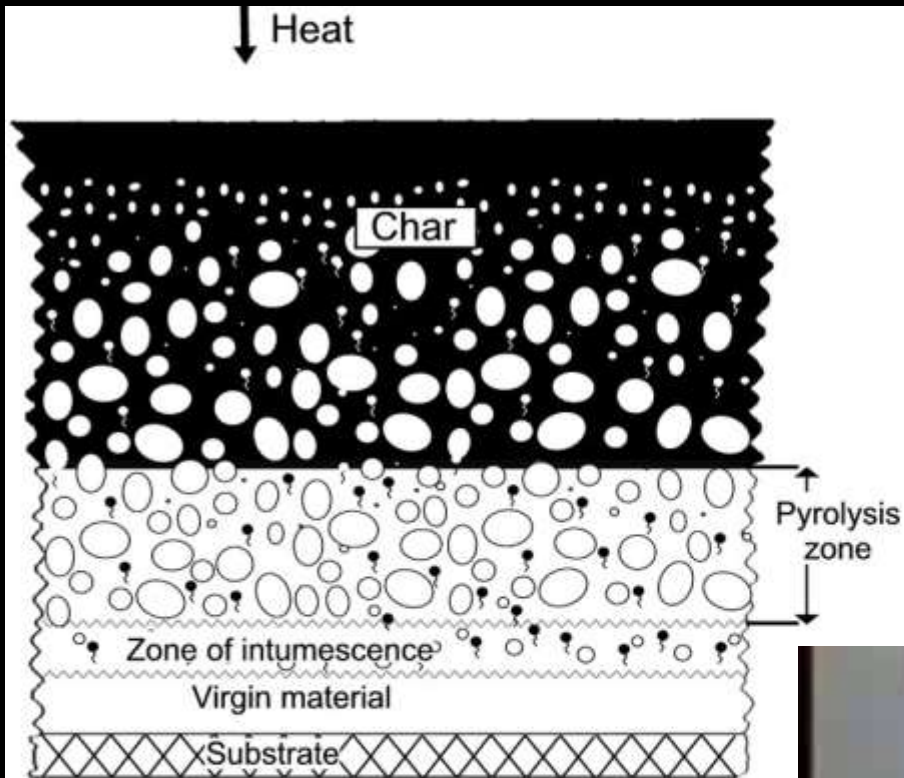
Post-crash fire simulation in full scale indoor at FAA

- Time consuming
- Expensive
- Slow development

Burnthrough test (NexGen)

Fire protection of CFRP

Intumescence?

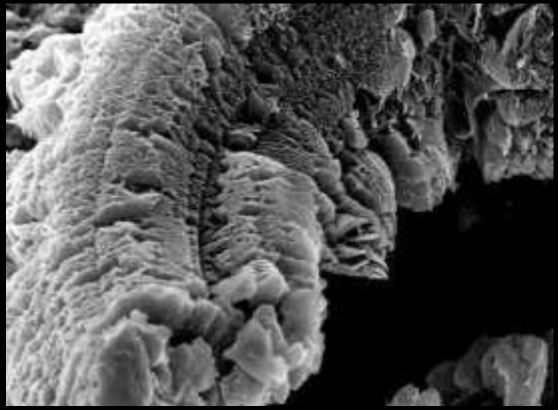


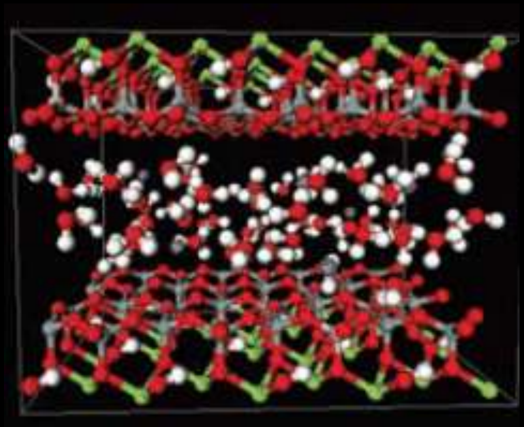
- **Formation of heat barrier**
- **Fire protection of materials?**

Silicone-based intumescent coating

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

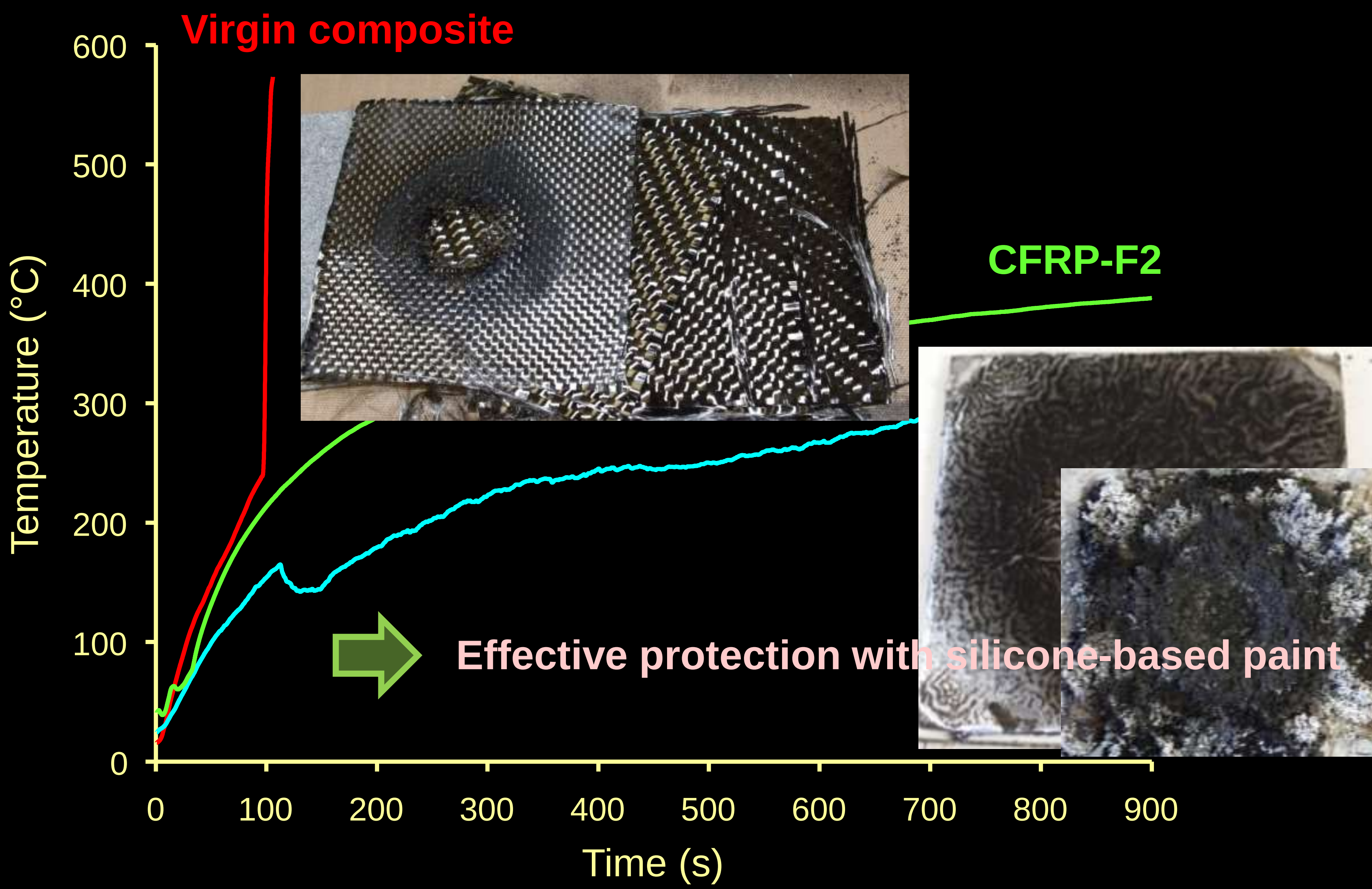
Silicone formulation	F1 – High intumescing coating	F2- Low intumescing coating
Silicone matrix	56%	56%
Expandable graphite	25%	-
Calcium carbonate	12%	37%
Clay	7%	7%





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

Protection by intumescence: 1000µm



Effective protection with silicone-based paint

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Protection by intumescence

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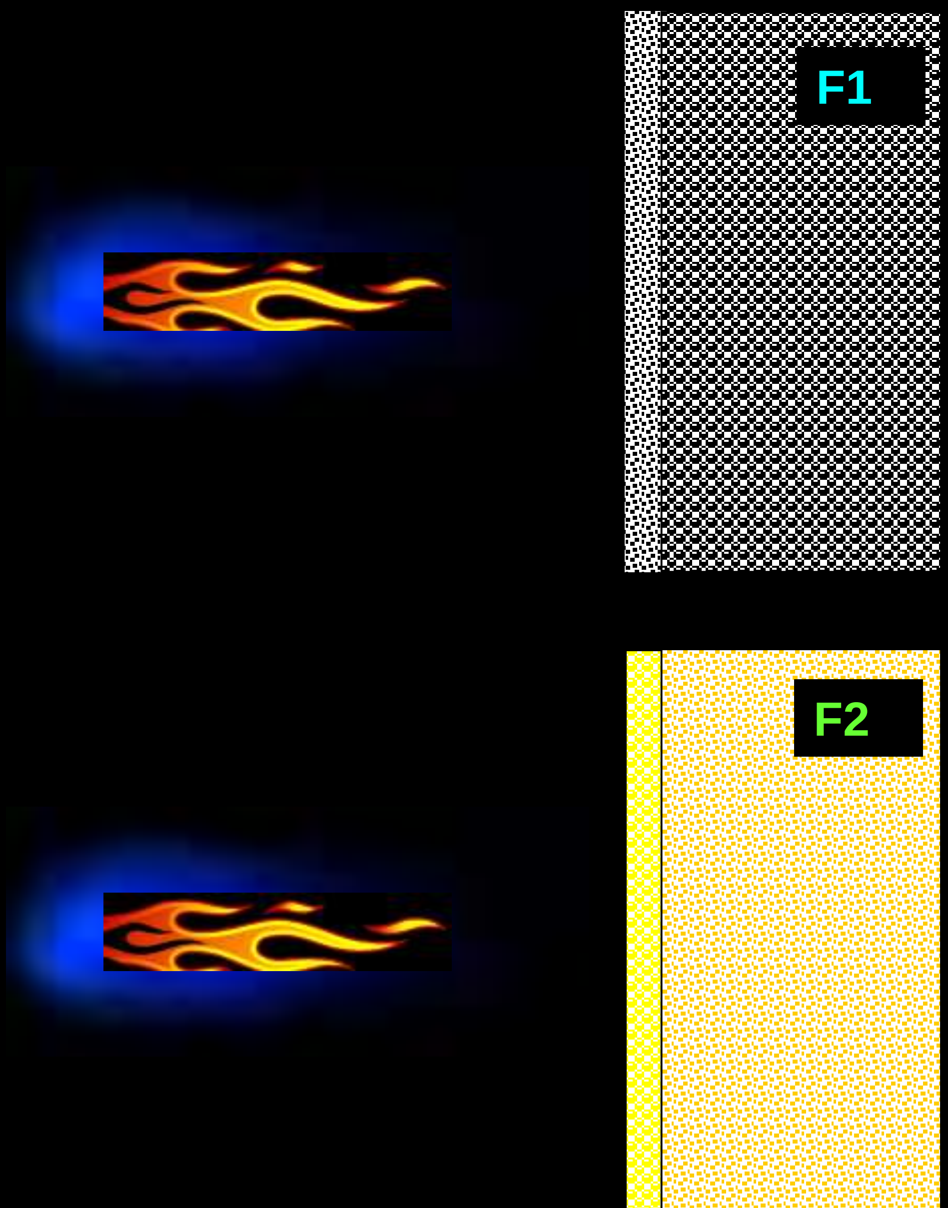
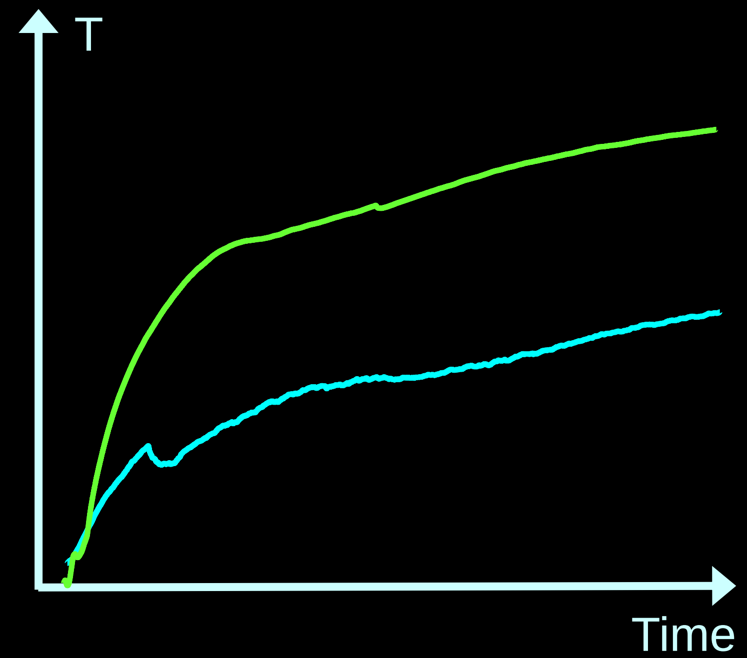
Virgin composite

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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Dimensionnal analysis: reducing the scale

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

Dimensional analysis: numbers

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

Dimensionless numbers are determined:

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

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

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

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

→ Biot numbers linked to the convection on the 2 faces

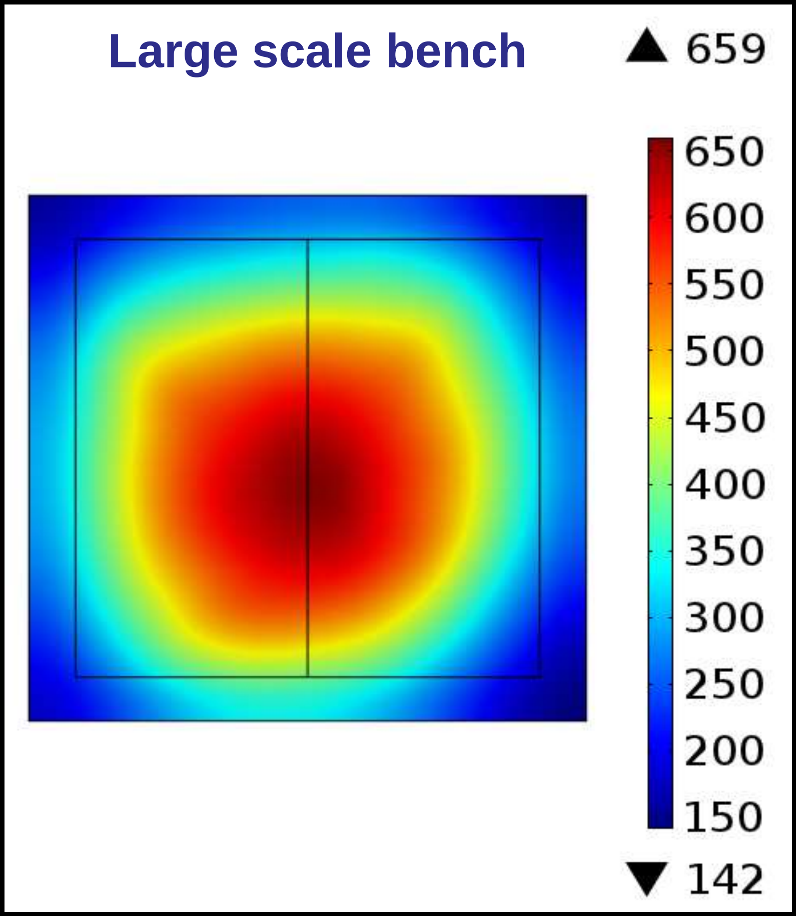
$$F_o^{ep} = \tau/\tau_{e_p} \qquad \tau_{e_p} = \frac{\rho C_p e_p^2}{k} \qquad N_r = \frac{e_p \sigma T^3_{amb}}{k}$$

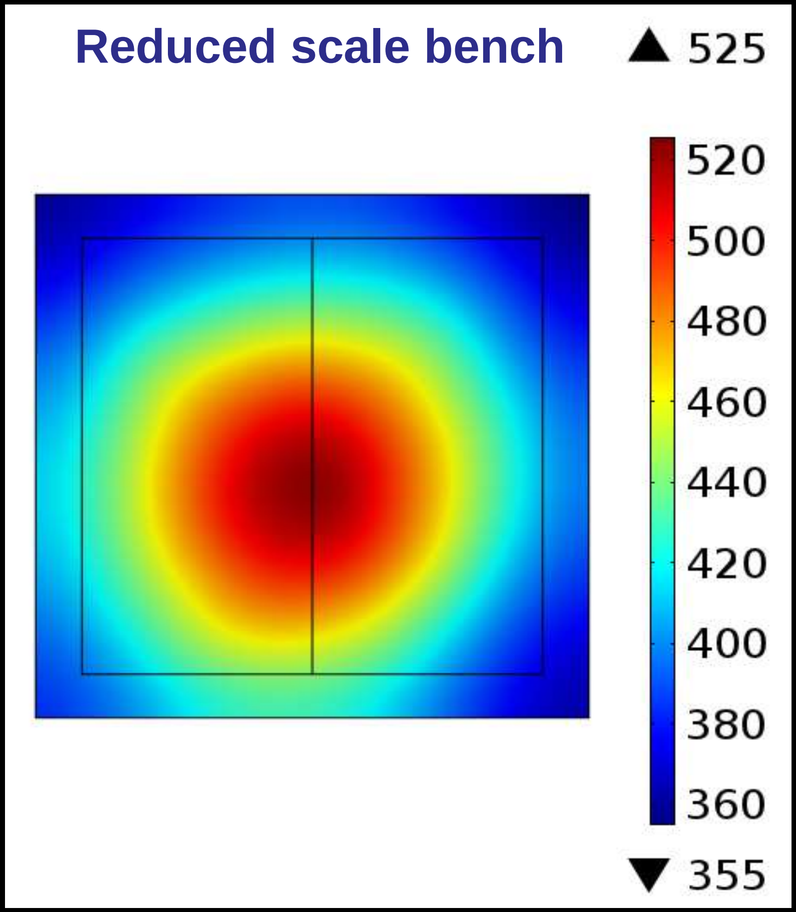
→ Fourier, time and radiative numbers

Dimensional analysis: scale reduction

Simulated scenario:

- Scale divided by 3 except sample thickness
- Same heat transfer
- Same duration





Lower temperature field for the small- scale bench

Small scale test: intumescent CFRP

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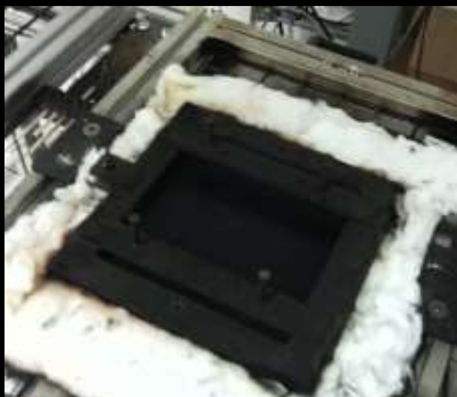
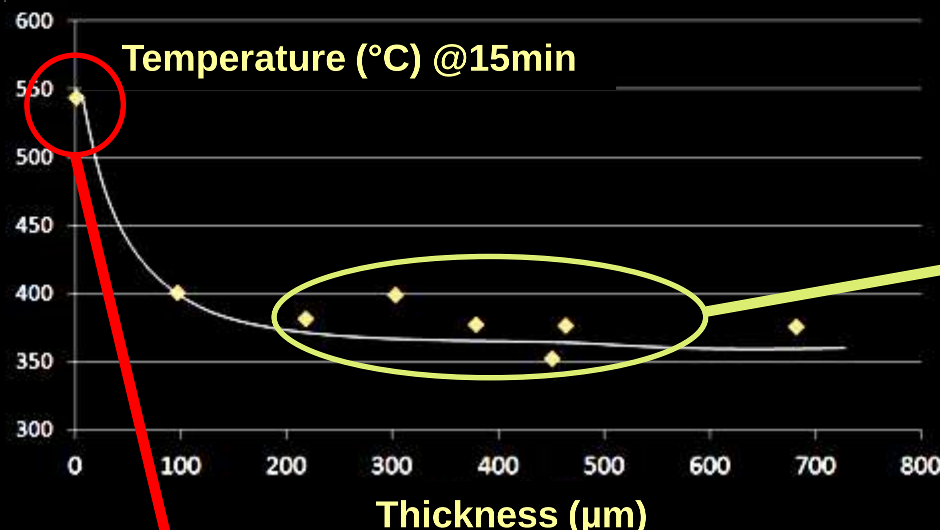
Evaluation of intumescent CFRP





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

Summary and Conclusions

- **Similitude:** ***scale reduction is not straight forward but correlation can be found simulating scale reduction***
- **Modeling:** ***numerical simulation and optimization for the development of small scale bench***
- **Intumescence:** ***efficient method to fire protect CFRP for aircraft and building applications***

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