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

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Recommended Citation
Serge Bourbigot, Fabienne Samyn, and Sophie Duquesne, "Composites on fire at reduced scale: evaluation, characterization and modeling" in "Composites at Lake Louise (CALL 2015)", Dr. Jim Smay, Oklahoma State University, USA Eds, ECI Symposium Series, (2016). http://dc.engconfintl.org/composites_all/66

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

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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)

- Time consuming
- Expensive
- Slow development

Post-crash fire simulation in full scale indoor at FAA

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

<table>
<thead>
<tr>
<th>Silicone formulation</th>
<th>F1 – High intumescing coating</th>
<th>F2- Low intumescing coating</th>
</tr>
</thead>
<tbody>
<tr>
<td>Silicone matrix</td>
<td>56%</td>
<td>56%</td>
</tr>
<tr>
<td>Expandable graphite</td>
<td>25%</td>
<td>-</td>
</tr>
<tr>
<td>Calcium carbonate</td>
<td>12%</td>
<td>37%</td>
</tr>
<tr>
<td>Clay</td>
<td>7%</td>
<td>7%</td>
</tr>
</tbody>
</table>

Protection by intumescence: 1000µm

Virgin composite

Effective protection with silicone-based paint
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)
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
- $T_{\text{flame}}$ of 1100°C
- Withstanding of the component for 5 min ⇒ fire proof
- Withstanding of the component for 15 min ⇒ fire resistant
Dimensional analysis: numbers

\[ \rho C \dot{T} - k \Delta \bar{T} = \frac{q_{av} - q_{ar}}{e_p} \]

\[ q_{ar} = h_{ar}(T - T_{amb}) + \varepsilon \sigma (T^4 - T_{amb}^4) \]

\[ q_{av} = h_{av}(x, y)(T_g - T) + C(x, y) \sigma (T_f^4 - T^4) - \varepsilon \sigma (T^4 - T_{amb}^4) \]

Dimensionless numbers are determined:

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

\[ \frac{\tau_e p \partial \tilde{T}}{\tau} - \left( \frac{e_p}{L} \right)^2 \Delta \tilde{T} = B_{iav} \left( \frac{T_g}{T_{amb}} - \tilde{T} \right) + C N_r \left( \left( \frac{T_f}{T_{amb}} \right)^4 - \tilde{T}^4 \right) - 2\varepsilon N_r (\tilde{T}^4 - 1) - B_{iar} (\tilde{T} - 1) \]

\[ B_{iav} = \frac{e_p h_{av}}{k} \quad B_{iar} = \frac{e_p h_{ar}}{k} \]

\[ F_{oep} = \frac{\tau}{\tau_{ep}} \quad \tau_{ep} = \frac{\rho C_p e_p^2}{k} \quad N_r = \frac{e_p \sigma T_{amb}^3}{k} \]

Biot numbers linked to the convection on the 2 faces

\[ \tau : \text{duration of the experiment} \]

\[ L : \text{length of the plate} \]

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

Evaluation of intumescent CFRP

<table>
<thead>
<tr>
<th>Thickness (µm)</th>
<th>Temperature (°C) @15min</th>
</tr>
</thead>
<tbody>
<tr>
<td>300</td>
<td>500</td>
</tr>
<tr>
<td>400</td>
<td>450</td>
</tr>
<tr>
<td>500</td>
<td>400</td>
</tr>
<tr>
<td>600</td>
<td>350</td>
</tr>
<tr>
<td>700</td>
<td>300</td>
</tr>
</tbody>
</table>

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

- **Similitude**: *scale reduction is not straightforward 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*
H2020 ERC Advanced Grant (2.4 millions €):
FireBar-Concept
(Multi-conceptual design of fire barrier: a systemic approach)