

# Evolution du comportement mécanique de composites aéronautiques soumis à une agression thermique

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# Introduction

- Conditions critiques en service :  
Incendie de nacelle de moteur d'avion [*Bartlett, 2001*]



British Airways, septembre 2015



Orenair, février 2016



Korean Air, mai 2016

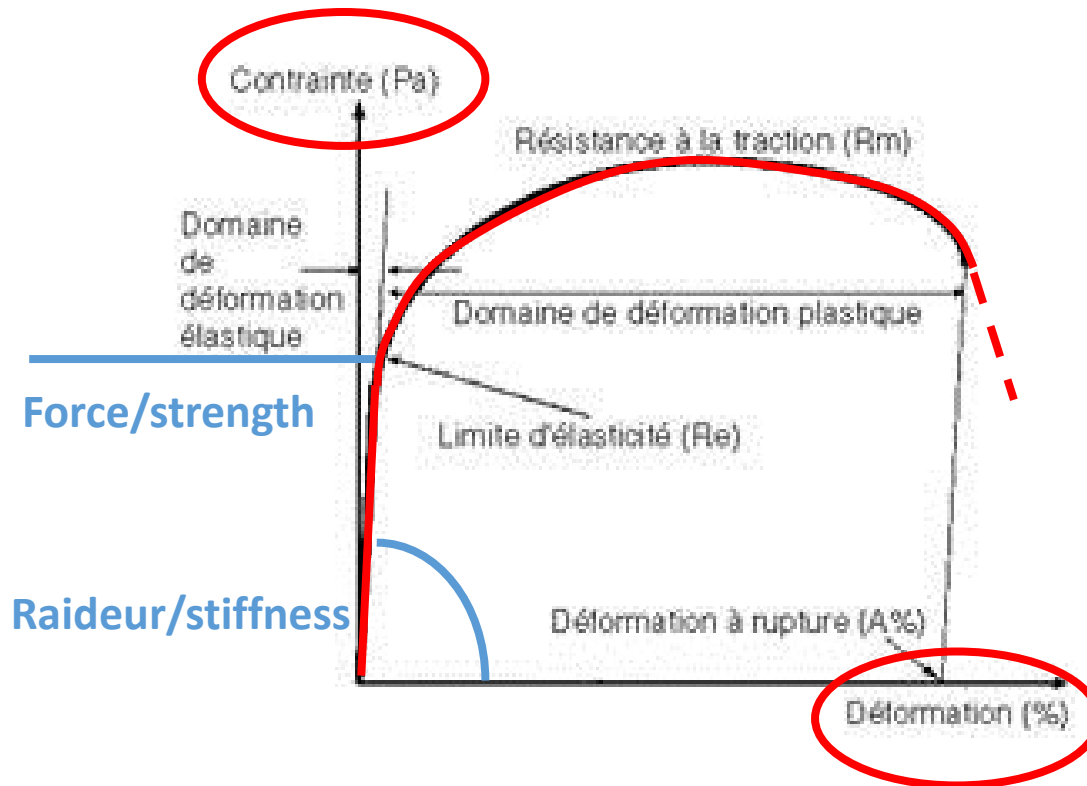


Singapour Airlines, juin 2016

Comprendre l'action 1- d'une flamme sur le résiduel 2- combinée d'une flamme et d'une sollicitation mécanique

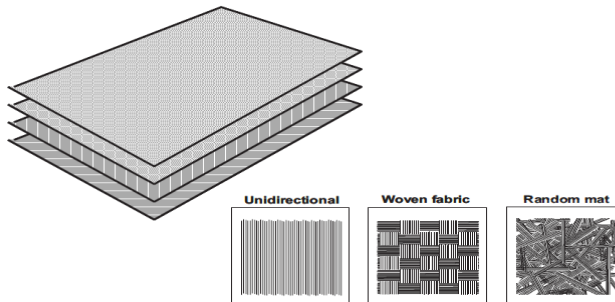
## Rappel de quelques notions

### Exemple: comportement en traction



# Les composites utilisés

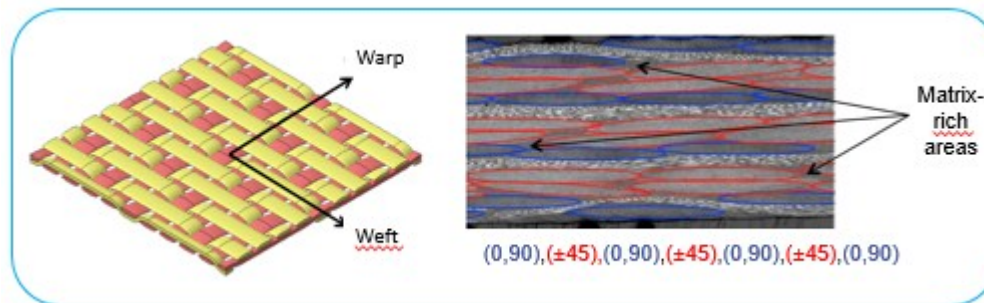
- Un matériau composite: matrice (résine ‘thermoset’ ou ‘thermoplastique’) + fibres (carbone, éléments minéraux, silice)



‘Fire Properties of Polymer Composite Materials’  
A.P. Mouritz, A.G. Gibson  
SOLID MECHANICS AND ITS APPLICATIONS  
Volume 143, Springer

Figure 6.1. Ply structure of laminated composites and common examples of ply architecture.

Results for: 7 plies carbon fabric-reinforced PPS or epoxy

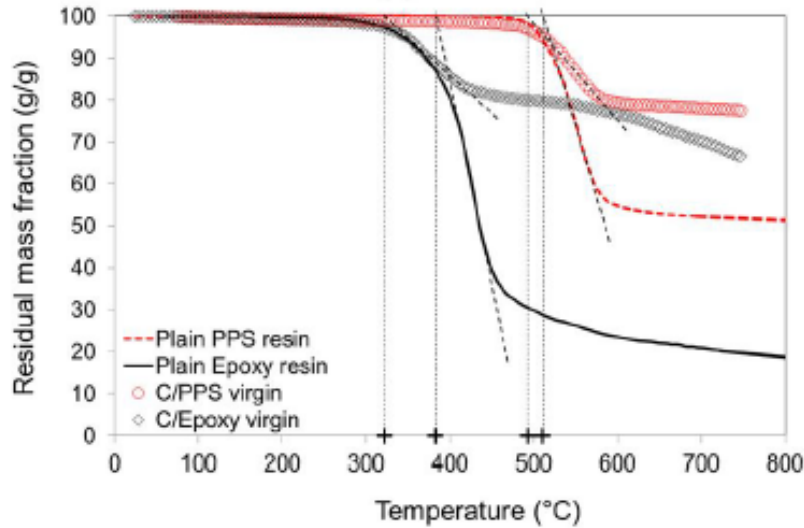


mass fraction of fibers is 58% in both materials  
Thickness: 2.2 mm

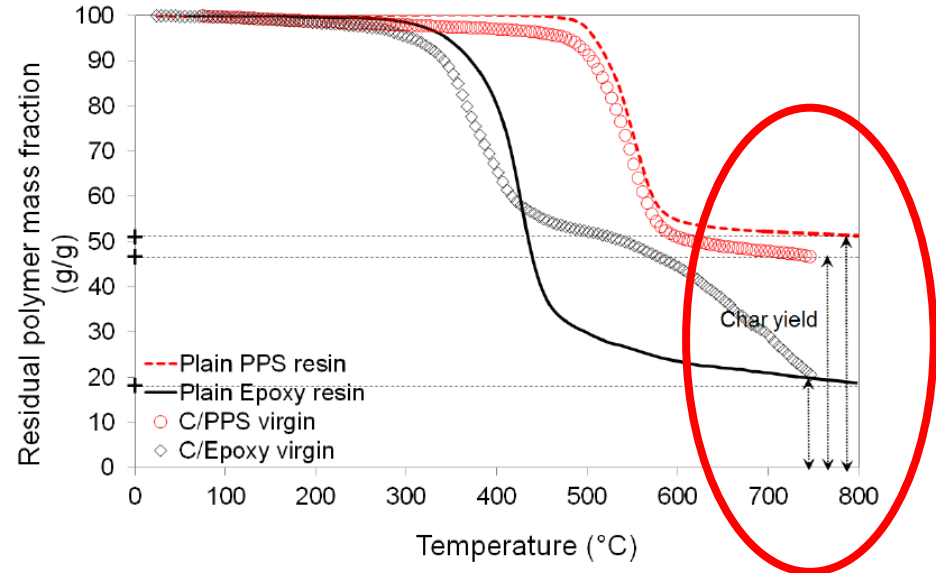
# Les composites utilisés

Dégradation: analyse ATG  
Masse(Tp)/ masse initiale

(a)



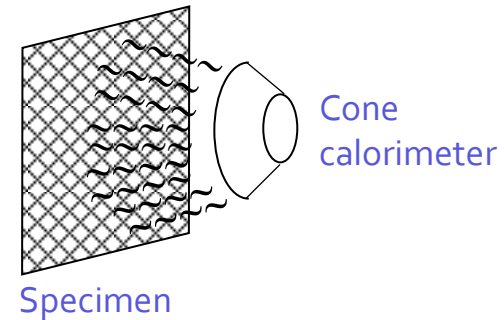
Dégradation: analyse ATG  
Masse(Tp)/ masse initiale de résine



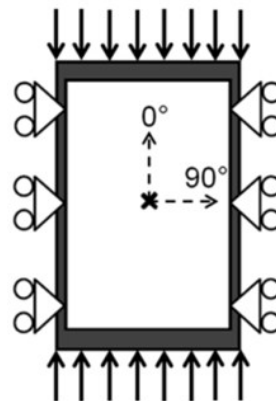
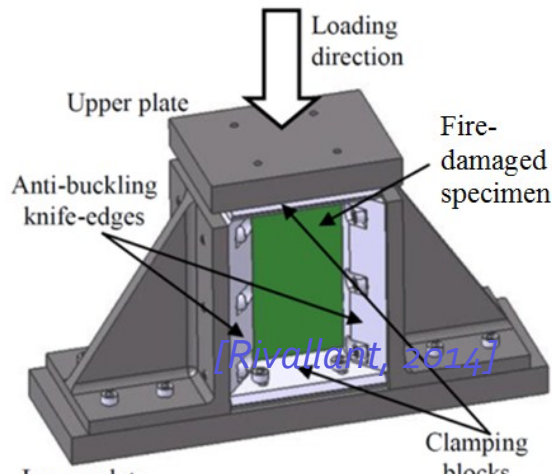
# First step

## Radiative thermal flux on sample ==> Mechanical Post-fire tests

- Fire exposure tests: cone calorimeter  
*Heat flux: 20 – 30 – 40 – 50 kW/m<sup>2</sup>*  
*Exposure time: 1-2-5 min*

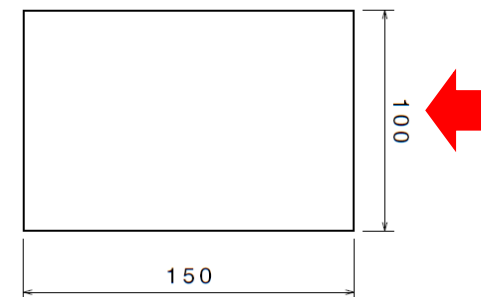


- Post-fire mechanical testing:  
*Boeing anti-buckling fixture*



Tensile tests specimens

Compressive tests specimens

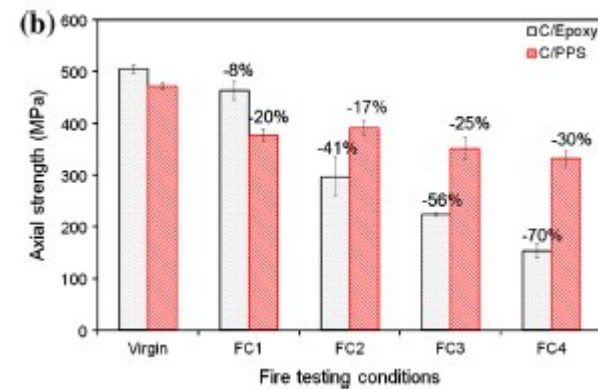
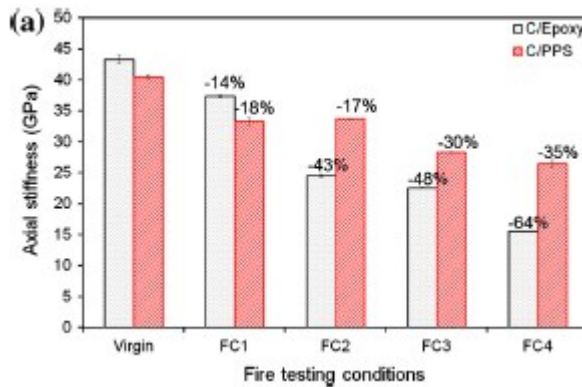
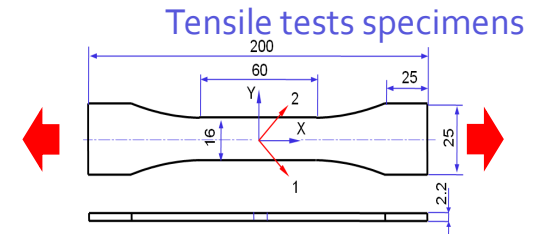


# First step

## Radiative thermal flux on sample ====> Mechanical Post-fire tests

[1] : Vieille *et al.* (2015)

[2] : Vieille *et al.* (2014)



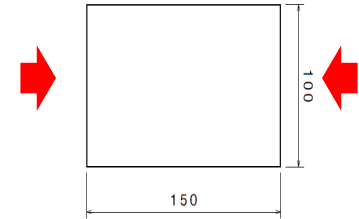
- FC1: 20 kW/m<sup>2</sup> for 2 min.
- FC2: 20 kW/m<sup>2</sup> for 5 min.
- FC3: 35 kW/m<sup>2</sup> for 2 min.
- FC4: 50 kW/m<sup>2</sup> for 1 min.

# First step

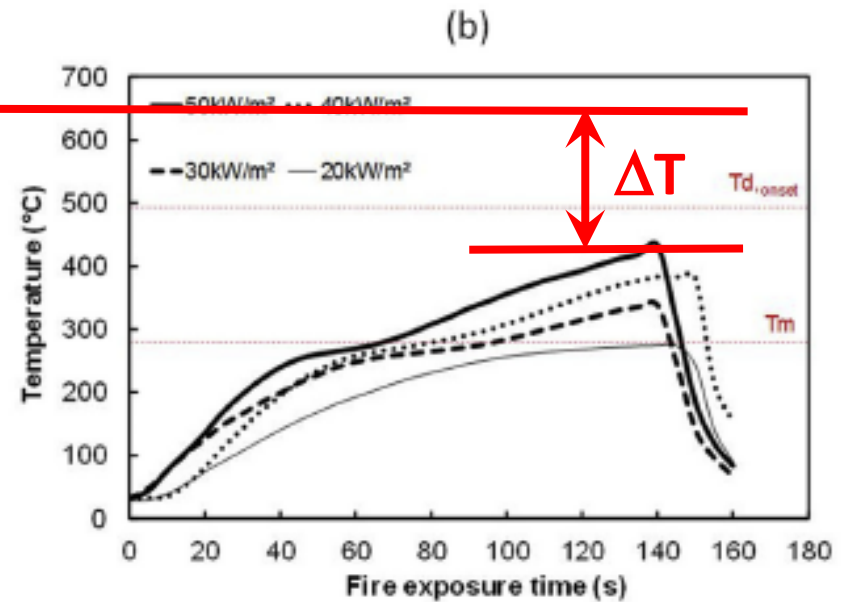
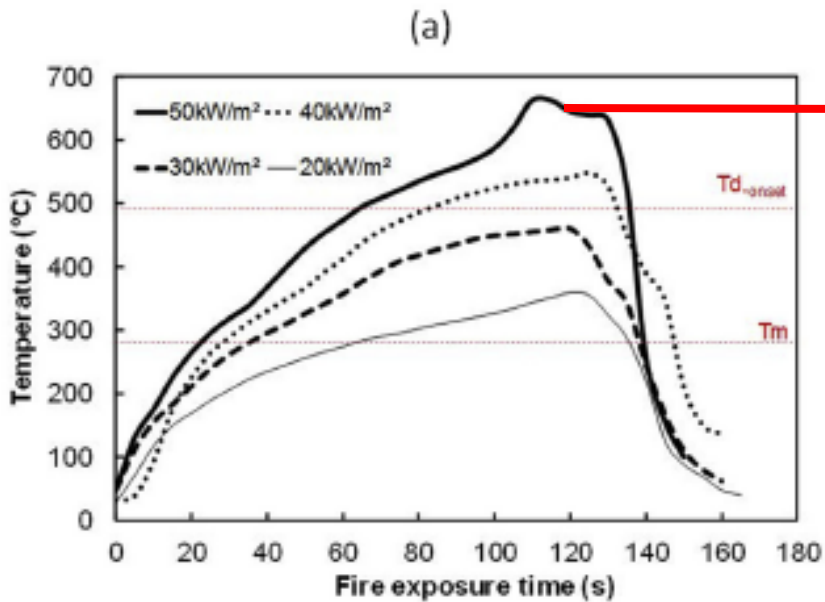
## Radiative thermal flux on sample ==> Mechanical Post-fire tests

[3] : Maaroufi et al. (2017)

Compressive tests specimen



### Characterization of post-fire compressive behavior PPS

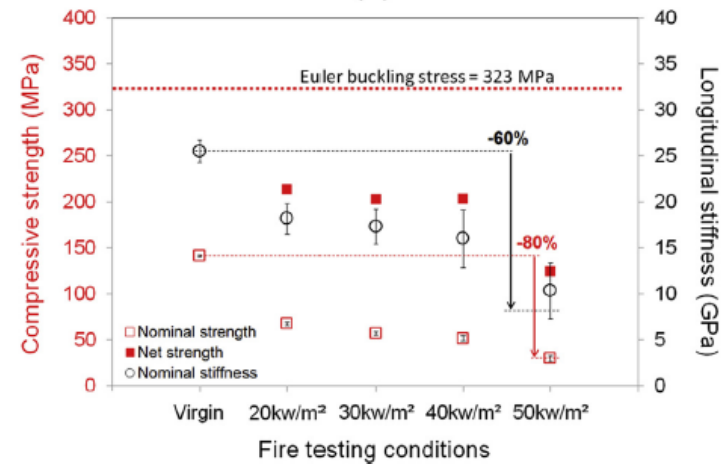
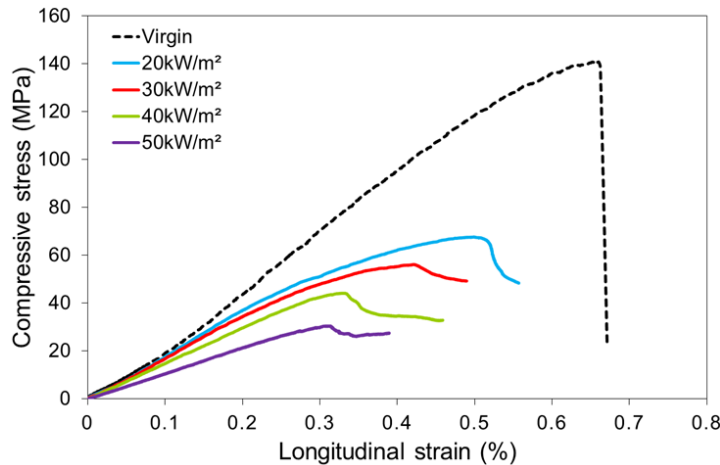




# First step

## Radiative thermal flux on sample ====> Mechanical Post-fire tests

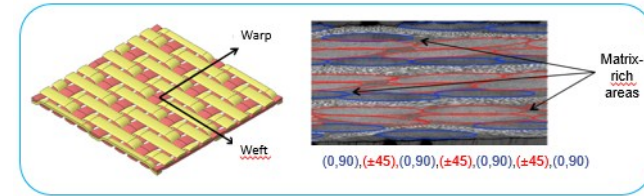
### Characterization of post-fire compressive behavior PPS



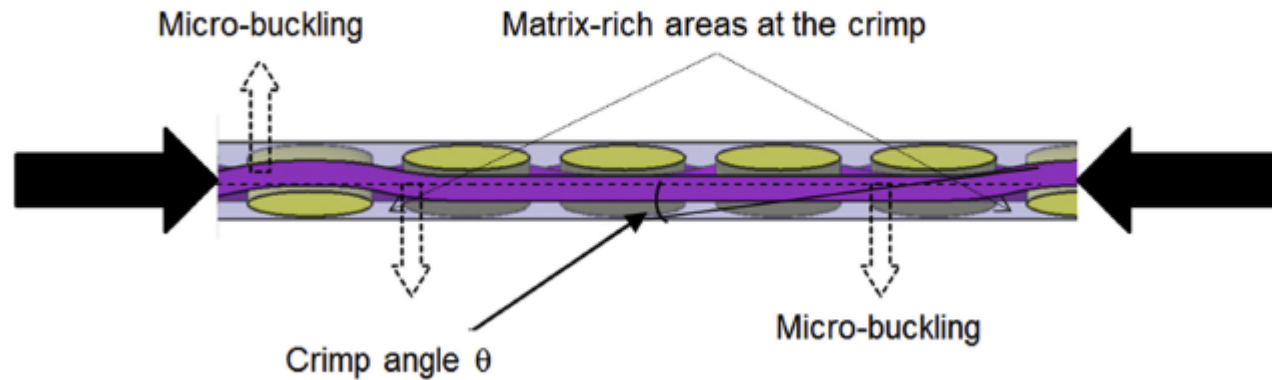
(a) Compression strain-stress curve (b) Decrease of properties after fire exposure

# First step

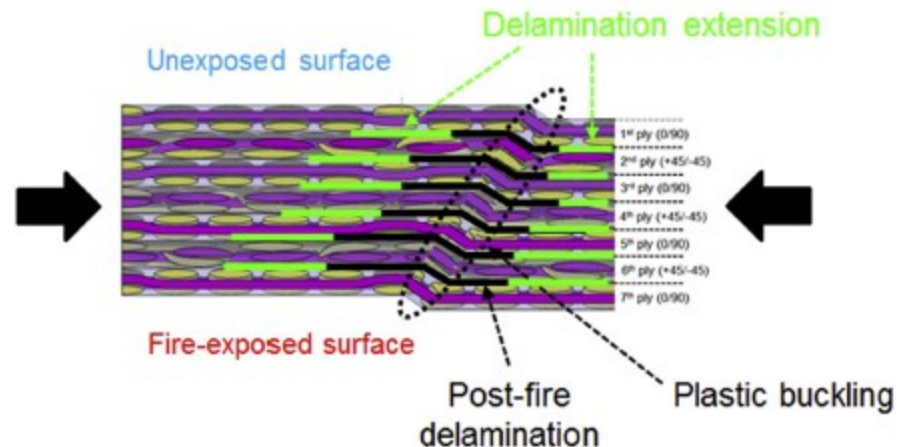
**Radiative thermal flux on sample  
====> Mechanical Post-fire tests**



(a) Microscopic buckling at woven-ply level



(b) Delamination and global plastic buckling at laminates level

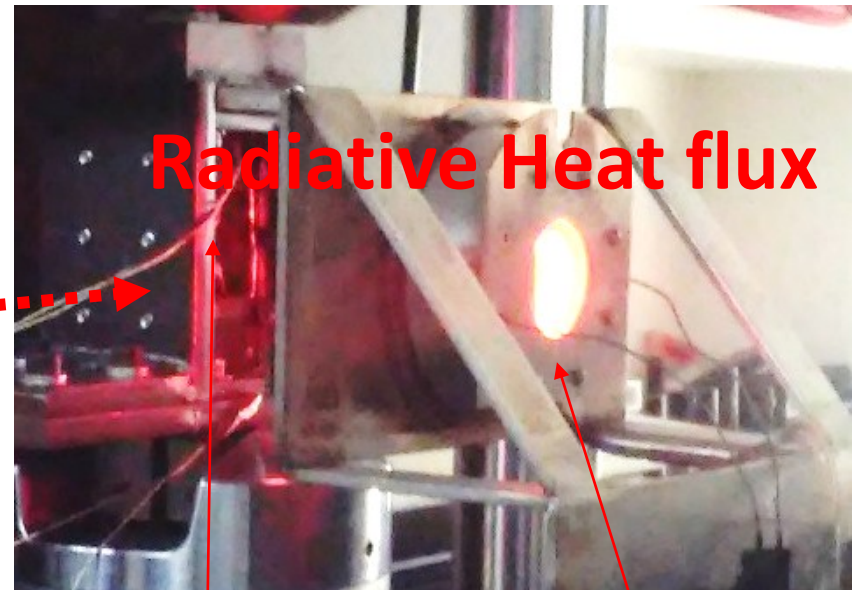
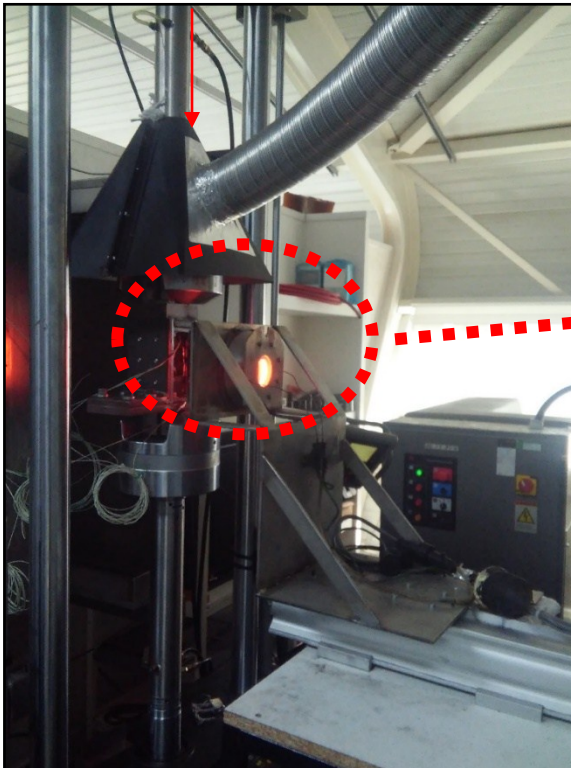


## Radiative thermal flux Combined with Mechanical tests

- compression **or tensil** under fire-exposure

Machine hydraulique d'essais  
mécaniques

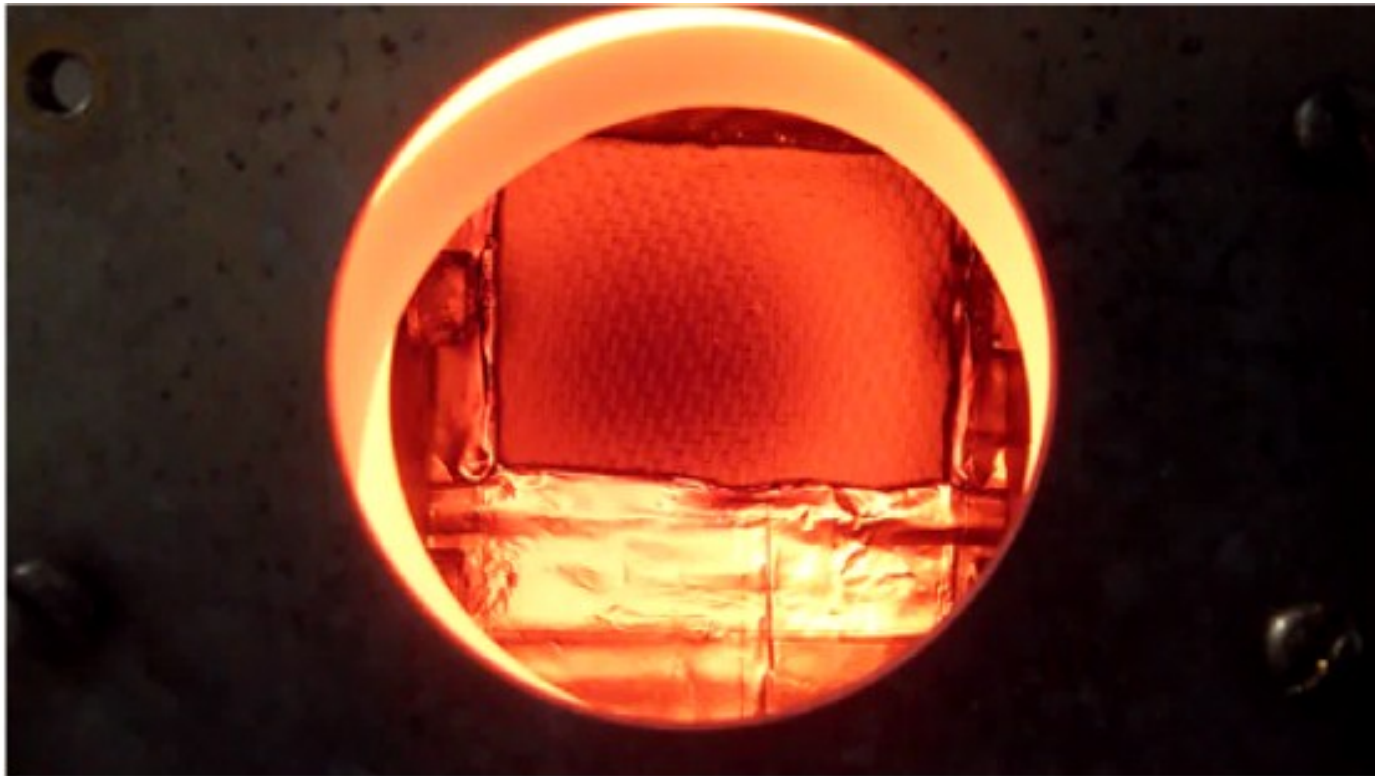
Hotte extraction fumées



Montage de  
fixation  
échantillon

Cone Calorimètre

## Radiative thermal flux Combined with Mechanical tests

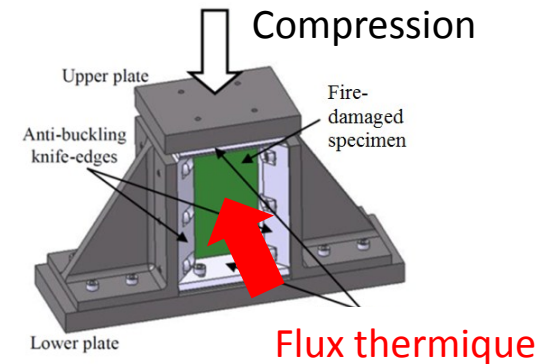
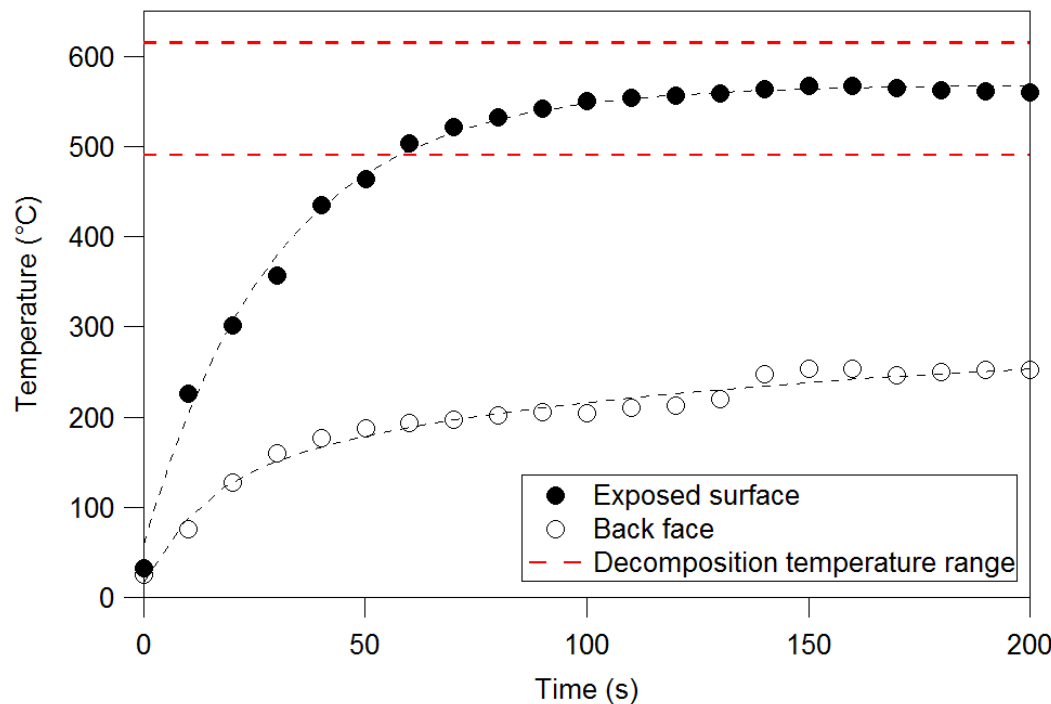


## Radiative thermal flux Combined with Mechanical tests

- Réalisation d'essais combinés (flamme + chargement mécanique)

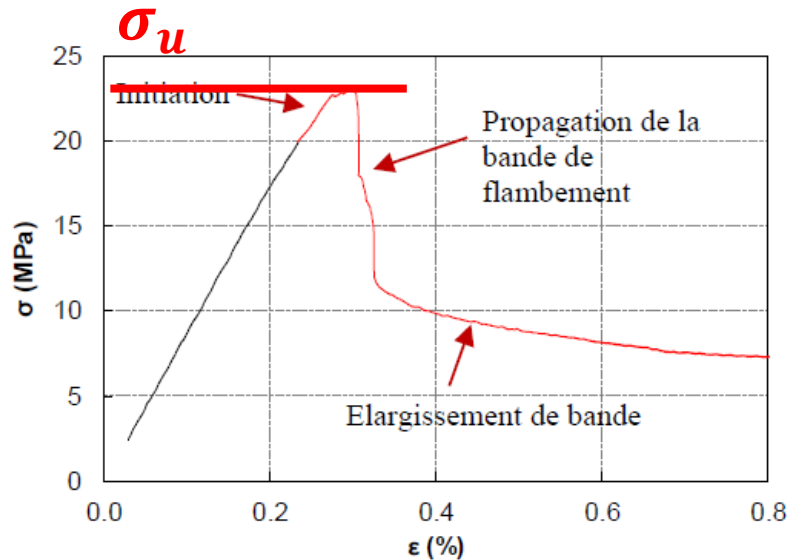
→ Compression + flux thermique

*Flux : 50kW/m<sup>2</sup>*

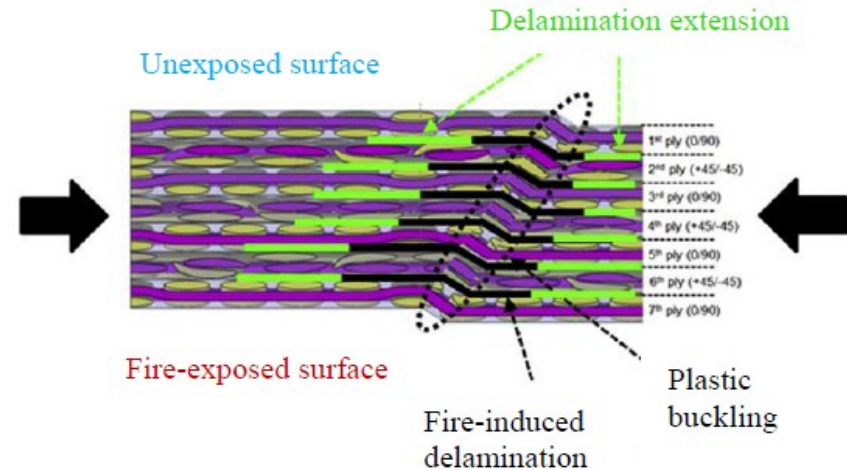


- Transient phase ~ 100s
- Decomposition temperature reached (at least) on the surface < 100s
- Thermal gradient ~ 300°C

## Radiative thermal flux Combined with Mechanical tests



Courbe  $\sigma = f(\epsilon)$  en compression monotone



Bande de flambement plastique

1. Initiation du flambement des fibres + cisaillement plastique matrice
2. Propagation de la bande de flambement
3. Elargissement de bande

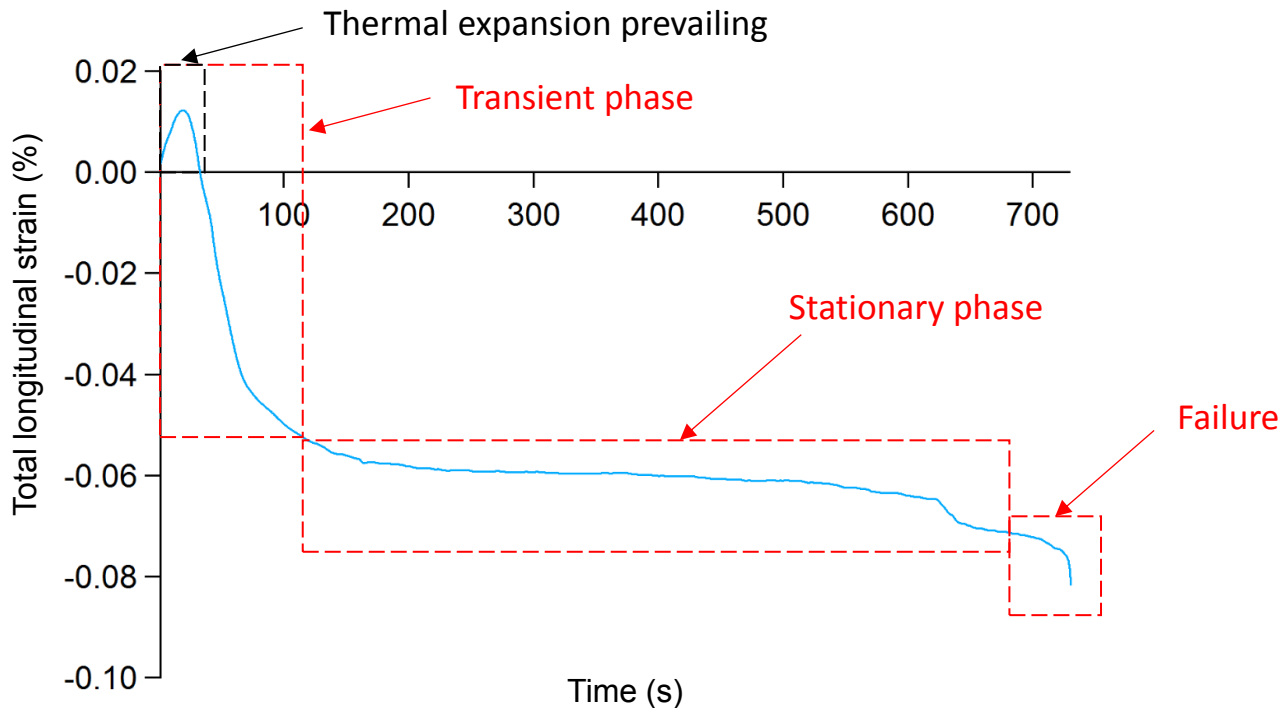


## Radiative thermal flux Combined with Mechanical tests

### *Compressive creep (macroscopical response) at 50% $\sigma_u$*

Thermal degradation : Process whereby the action of heat [...] causes a loss of mechanical properties

Thermal decomposition : Process of extensive chemical species changes caused by heat (ISO 13943)

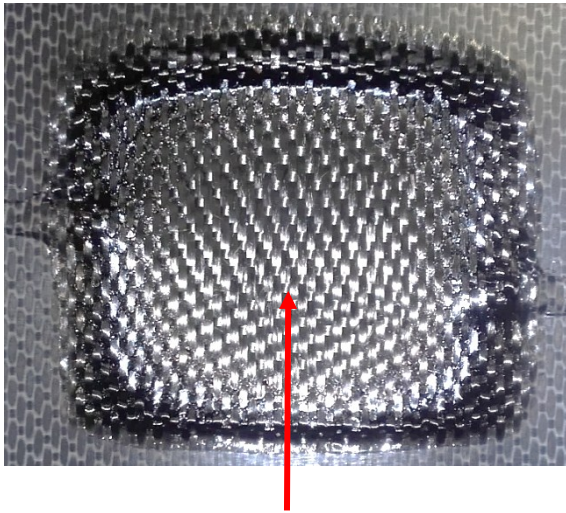


$$\epsilon = \epsilon_0 + \epsilon_{th.expansion} + \epsilon_{th.degradation} + \epsilon_{thermochemical} + \epsilon_{creep}$$

## Radiative thermal flux Combined with Mechanical tests

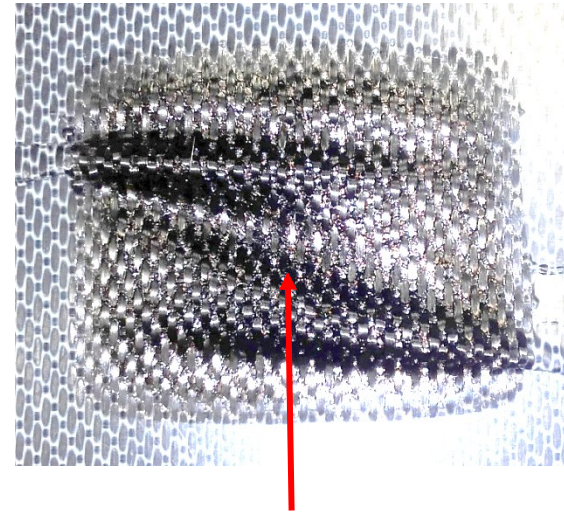
### Fluage tertiaire - Rupture

$$\sigma_{fluage} = 0,25 \sigma_u$$



Oxydation complète de la matrice sur la face exposée

$$\sigma_{fluage} = 0,75 \sigma_u$$



Pyrolyse partielle de la matrice

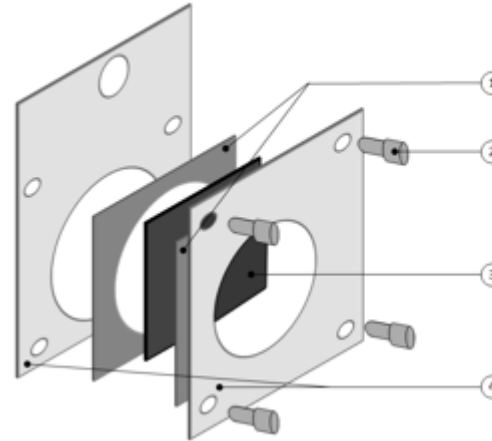




# Third step (in progress)

## With a Flame flux exposure

- Higher fluxes using a propane burner



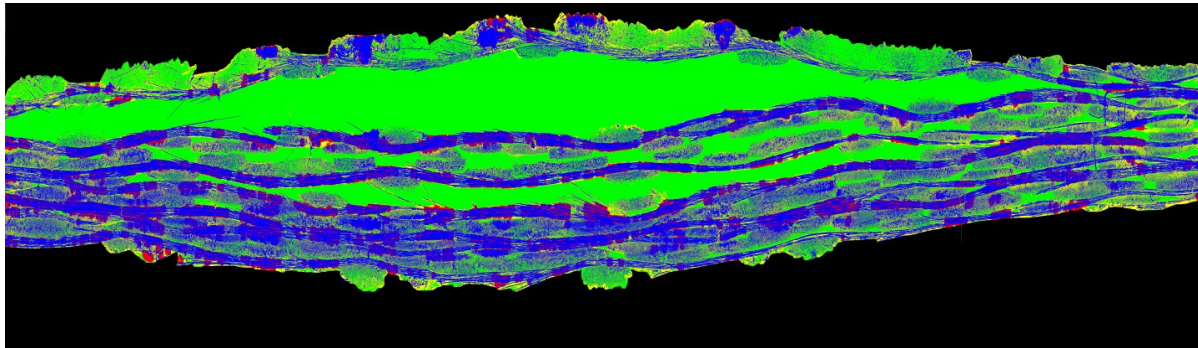
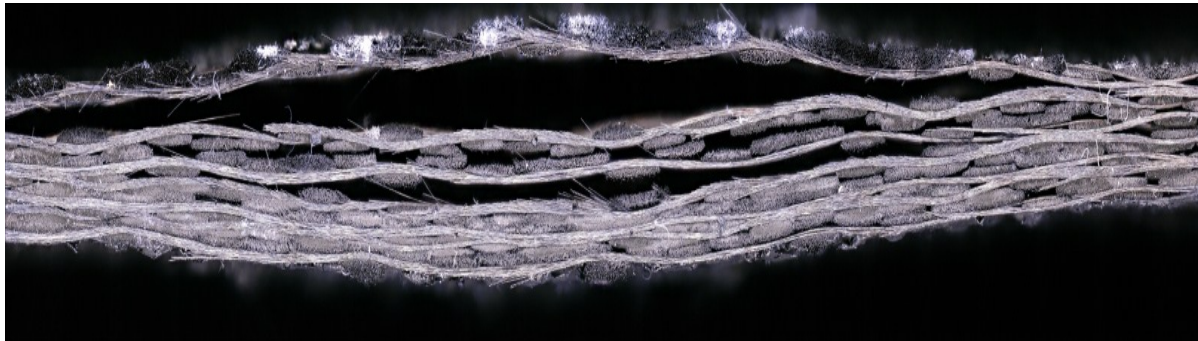
- (1) Isolation thermique
- (2) Vis de serrage
- (3) Coupon
- (4) Porte échantillon

- Fluxes: 116 – 200 kW/m<sup>2</sup>
- Thermal degradation analysis
- No mechanical test

# Third step (in progress)

## With a Flame flux exposure

Analyse des zones dégradées



Flamme ↑

Matrice and  
char 20.5%

Porosité 40%

Fibre 40%

Carbone/Epoxy  
106kW/m<sup>2</sup>  
90 secondes

- La décomposition des composites de faibles épaisseurs (qlq mm) est rapide: 100-200s
- Cela entraine un abattement des propriétés mécaniques, à la fois en traction et en compression
- En traction: cet abattement est plus faible pour les thermoplastiques
- La perte des propriétés mécaniques en compression est dépendante du niveau de flux
- Pour les composites avec des fibres tissées, l'évolution des propriétés mécaniques Sous une compression passe par des microflambements, privilégiés dans les zones de recouvrement, qui ensuite se propagent à l'ensemble des fibres
- Les études avec une agression sous flamme devraient apporter des informations supplémentaires pour comprendre le comportement des composites lors d'un accident réel