Flammability Properties of Aircraft Carbon-fiber Structural Composite

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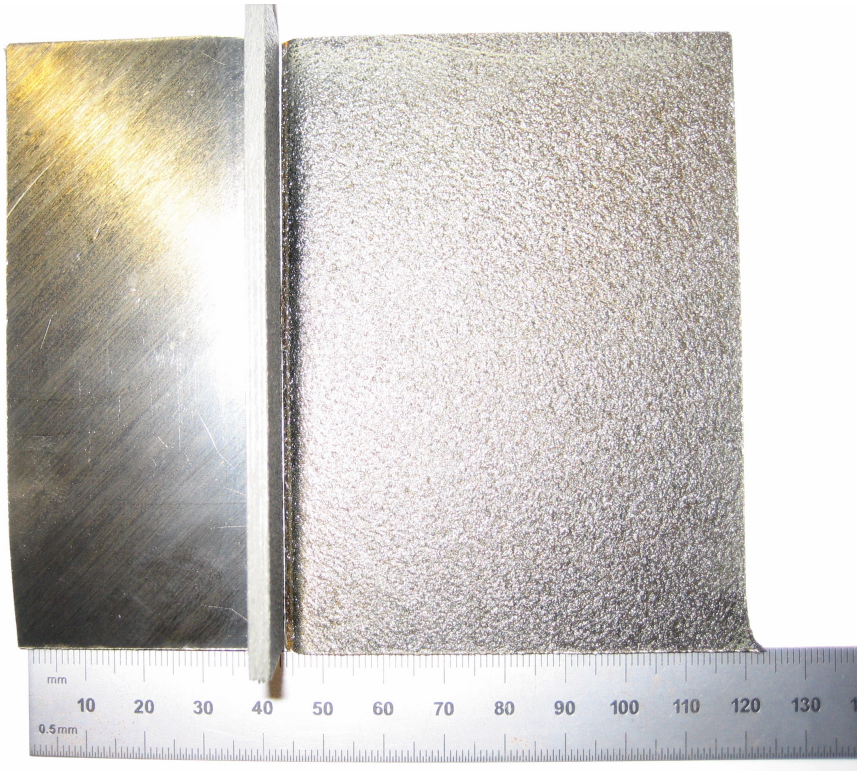
Composite Material

- Consider Material BMS 8-276, Toray Composites (America)
  - Carbon fiber density = 1750 kg/ m^3
  - Volume fraction of carbon in the composite = 0.60
  - Resin density = 1220 kg/ m^3
  - Char fraction (typical) of resin alone in flaming combustion = 0.25



Facsimile to Boeing 787

- No surprises in the performance of a new material
- Measure basic flammability performance
- Establish data and properties to explain fire scenario hazards

Objectives

- Measure fire behavior over range of heat flux, to 100 kW/m^2
- Establish behavior and limits
  - Ignition
  - Flame spread
  - Burning rate
  - Carbon smoldering
- Determine properties useful in modeling

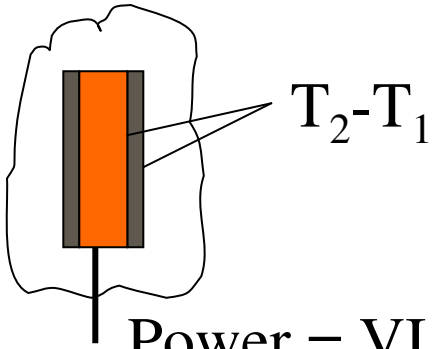
Properties

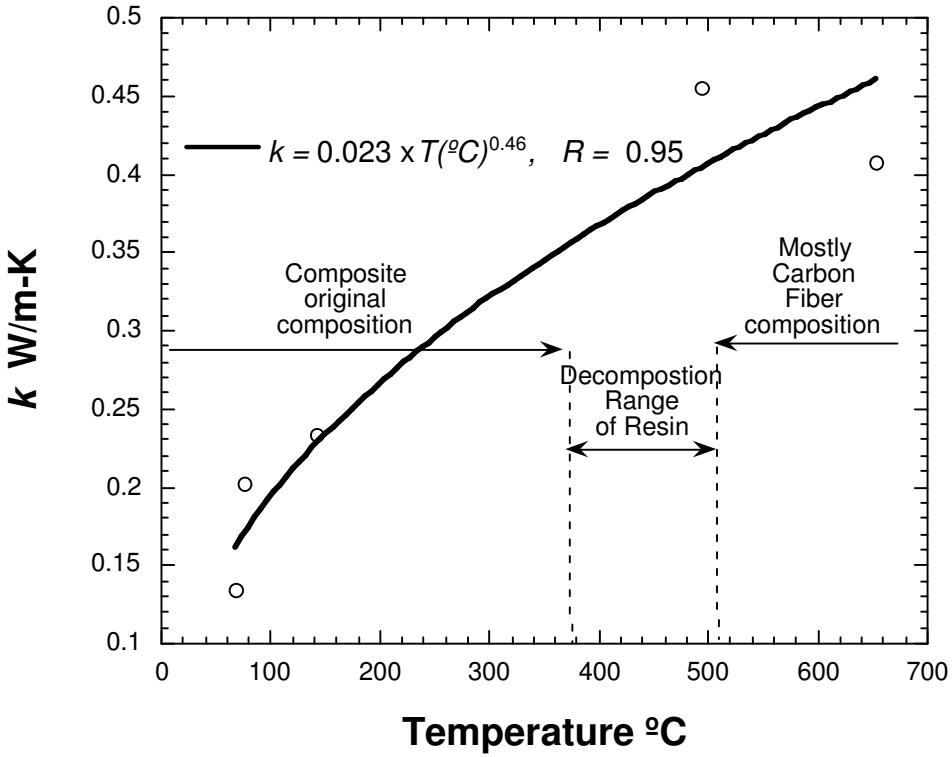
- Thermal conductivity
- Specific heat
- Heat of decomposition
- Kinetics
- Combustion

Thermal Conductivity

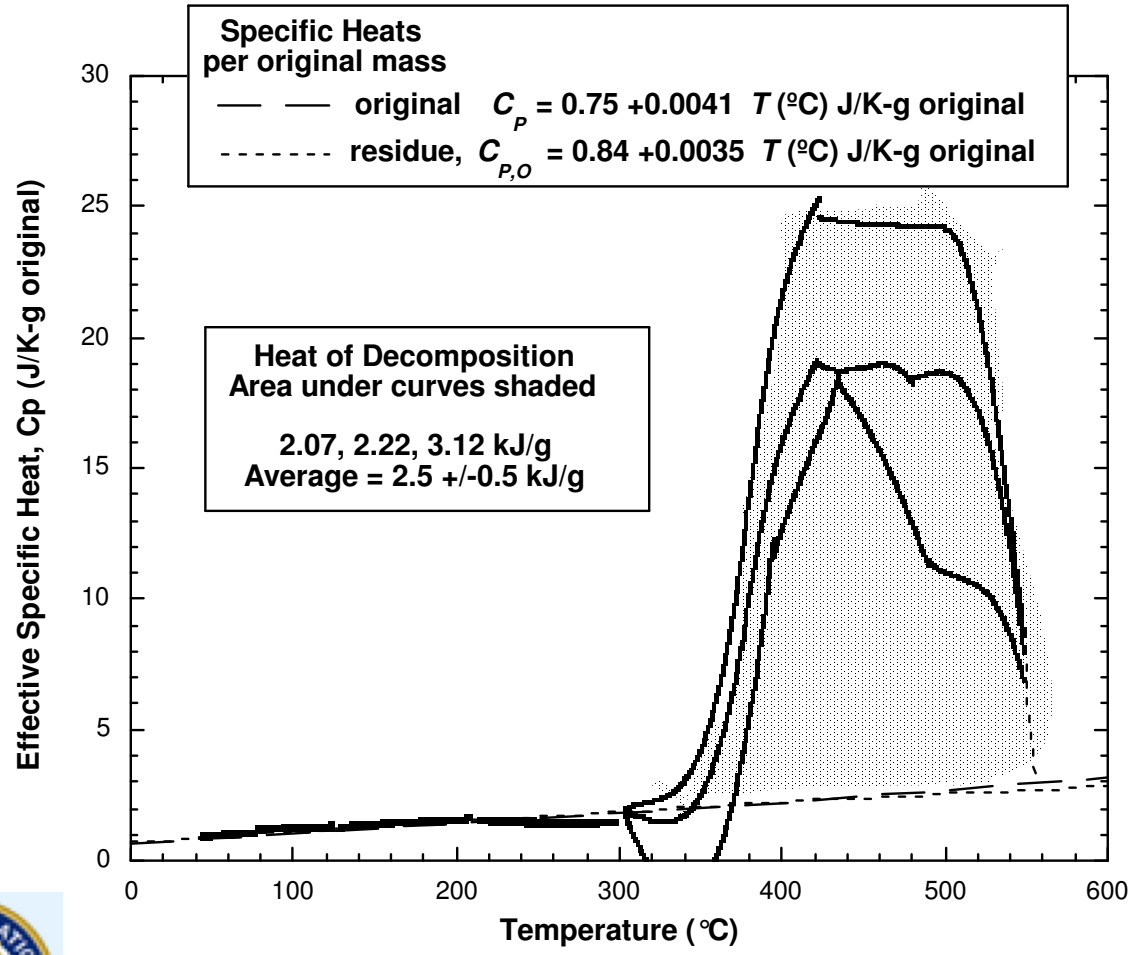
$$k = \frac{q'' \delta}{\Delta T}$$

~ -20% error
Due to heat losses



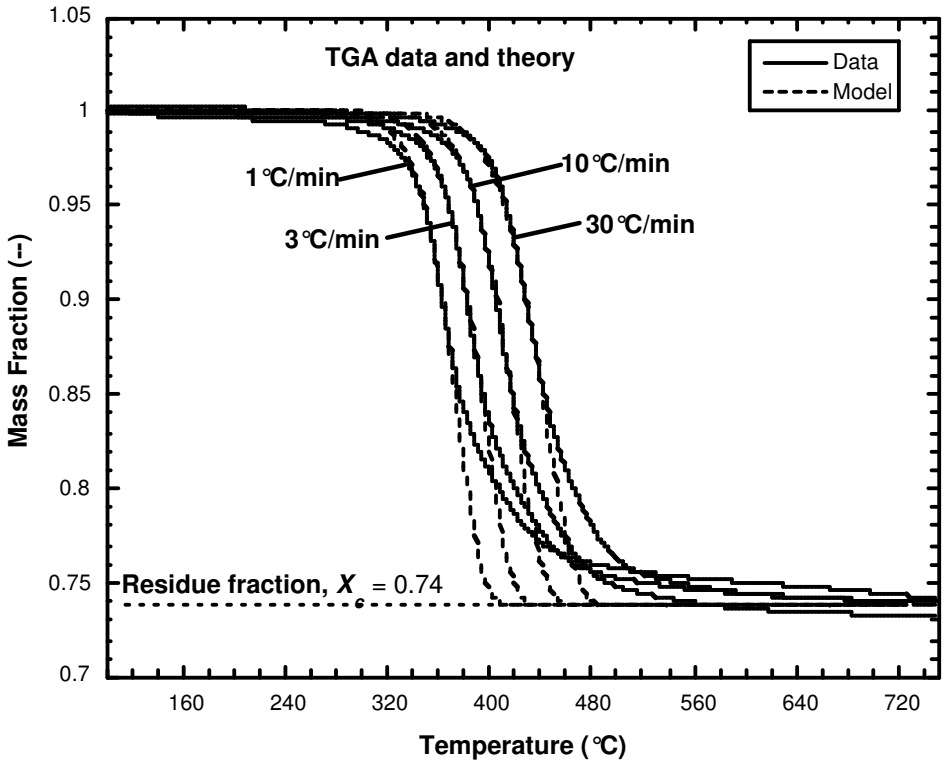


Thermodynamic properties



- Specific heat
- Heat of decomposition
- By DSC

Decomposition properties



- By TGA
- First order Arrhenius

$$\frac{d\alpha}{dt} = \frac{(1-\alpha)}{(1-X_c)} k(T)$$

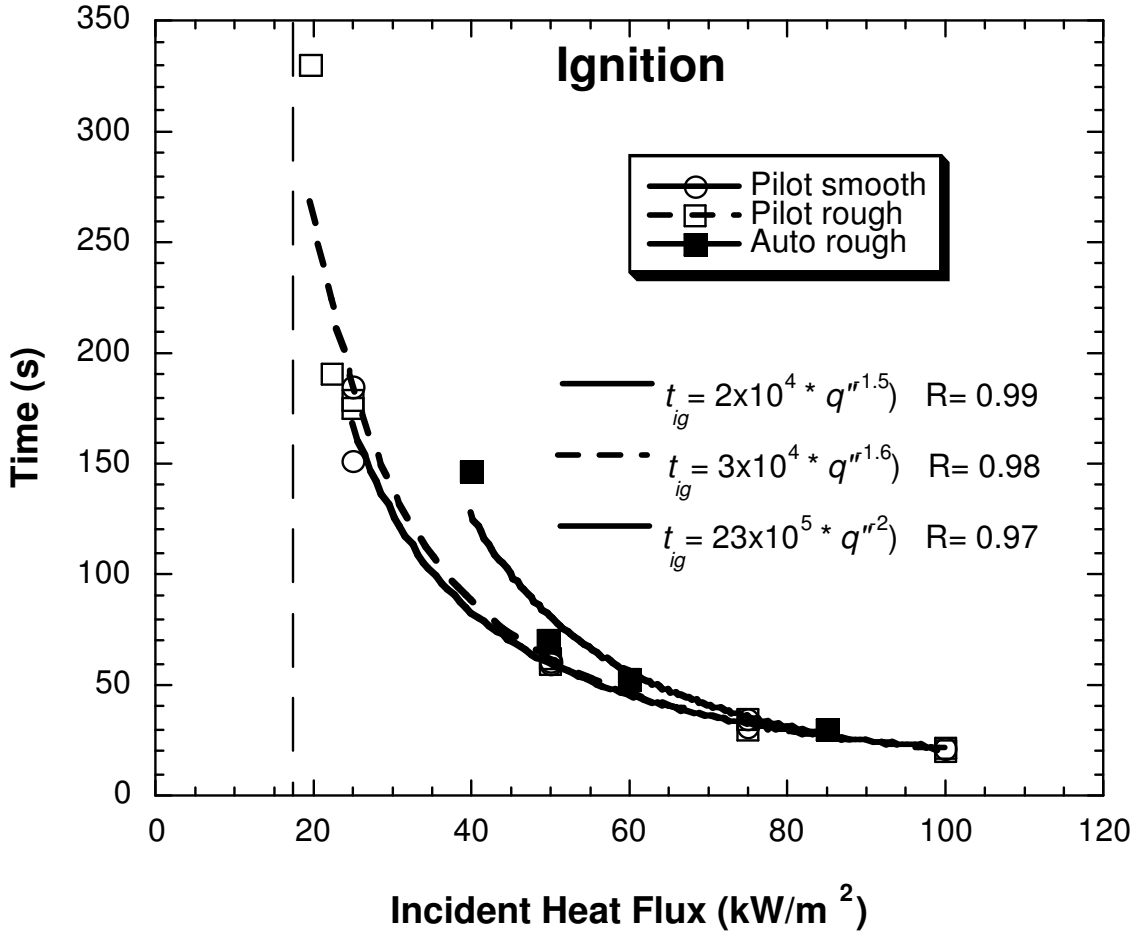
$$\alpha = \frac{m - m_i}{m_f - m_i} = \frac{m/m_i - 1}{X_c - 1}$$

$$k = a_p e^{-E_a/RT}$$

$$E = 182 \text{ kJ/mol}$$

$$a_p = 9.67 \text{ x } 10^{10} \text{ s}^{-1}$$

Ignition: by radiation

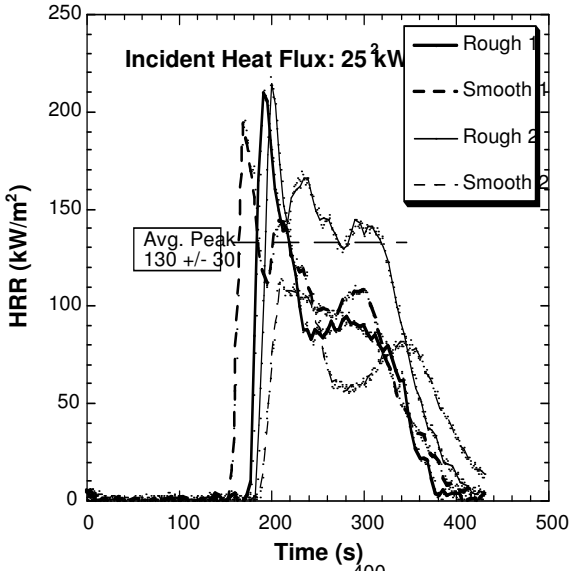


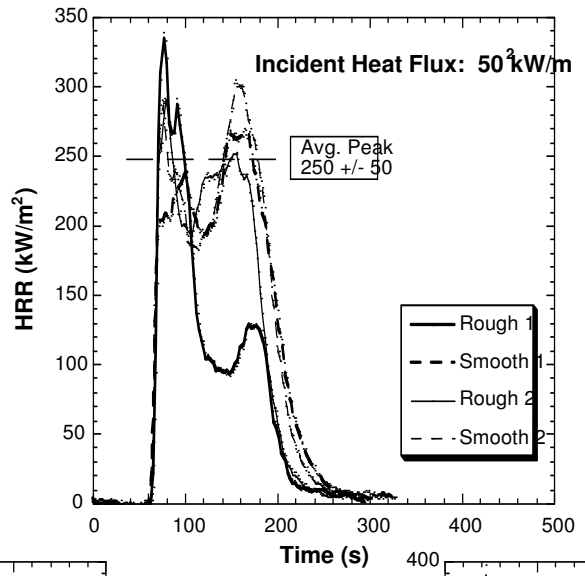
Auto

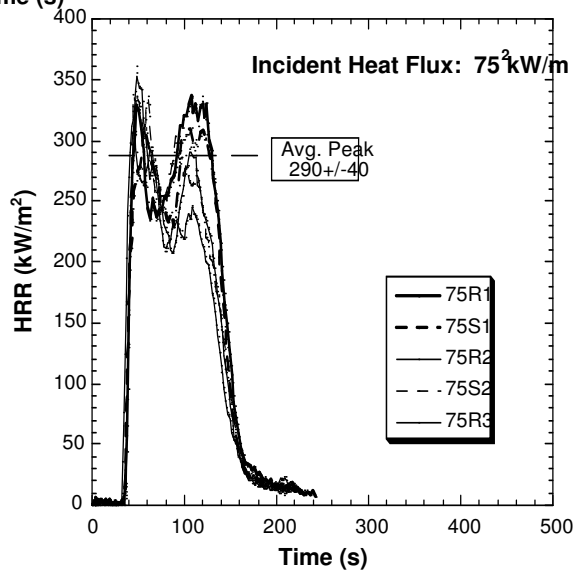
&

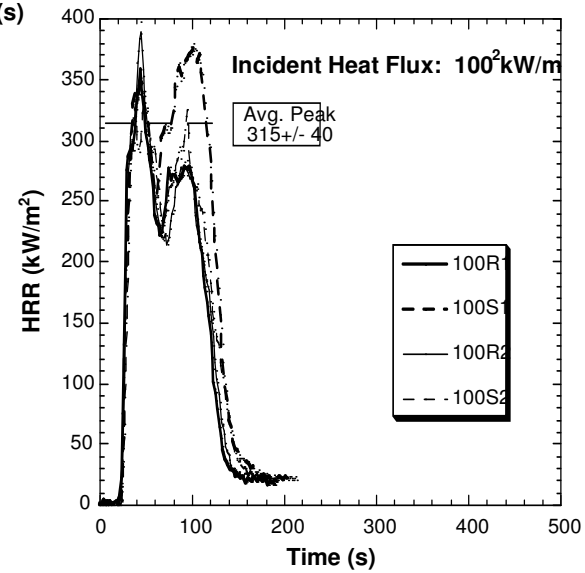
Piloted

Burning: Cone Calorimeter

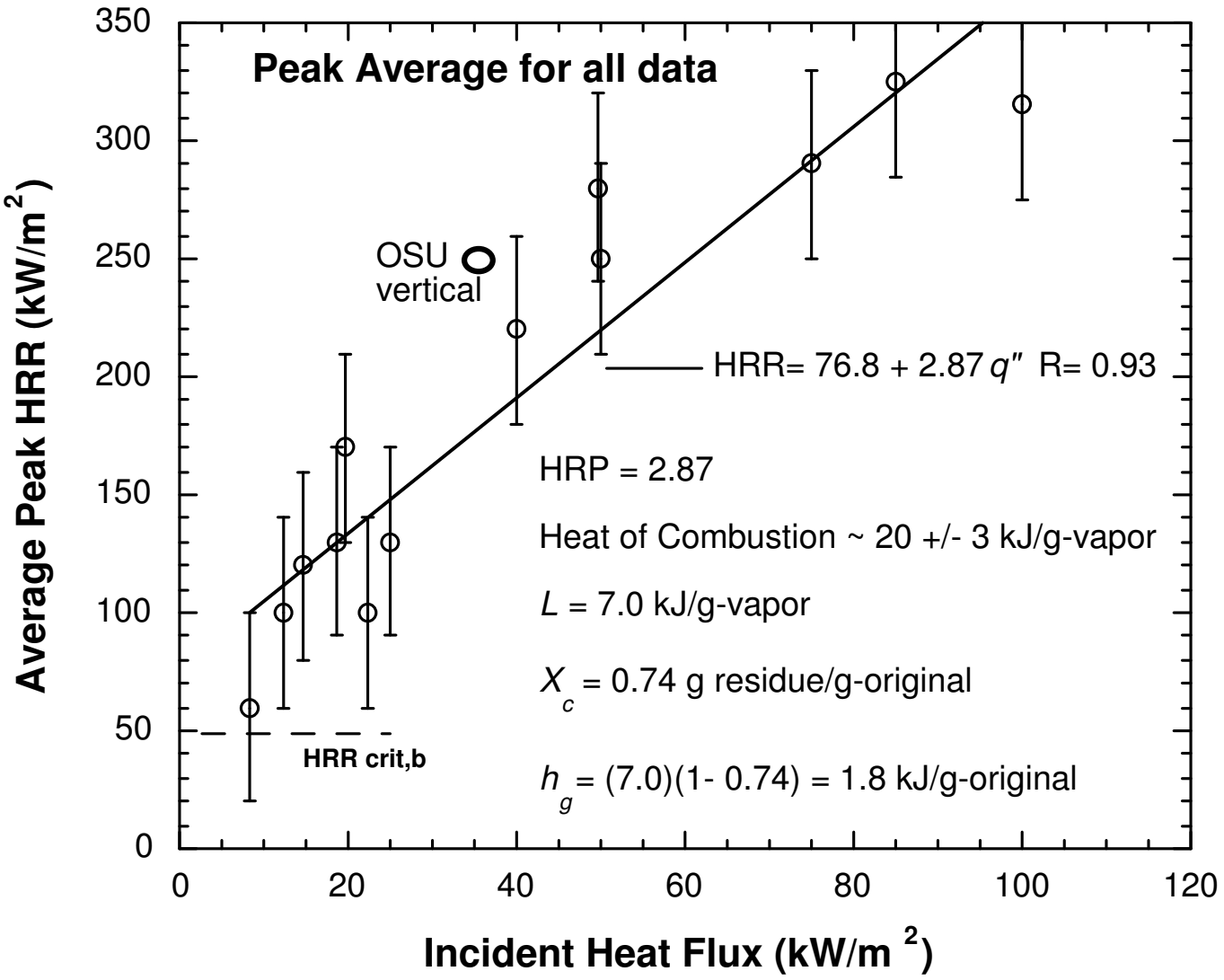




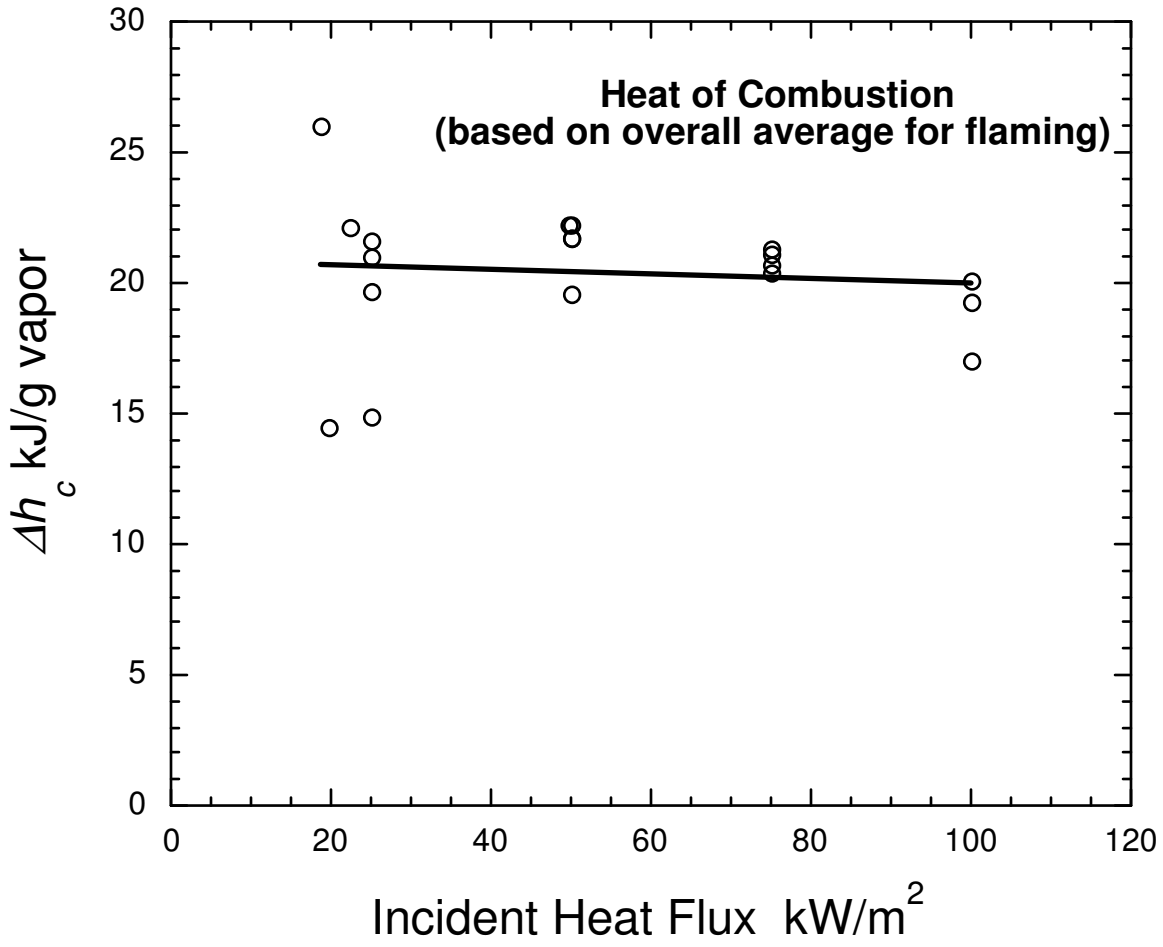




Average Burning Rate



Heat of Combustion

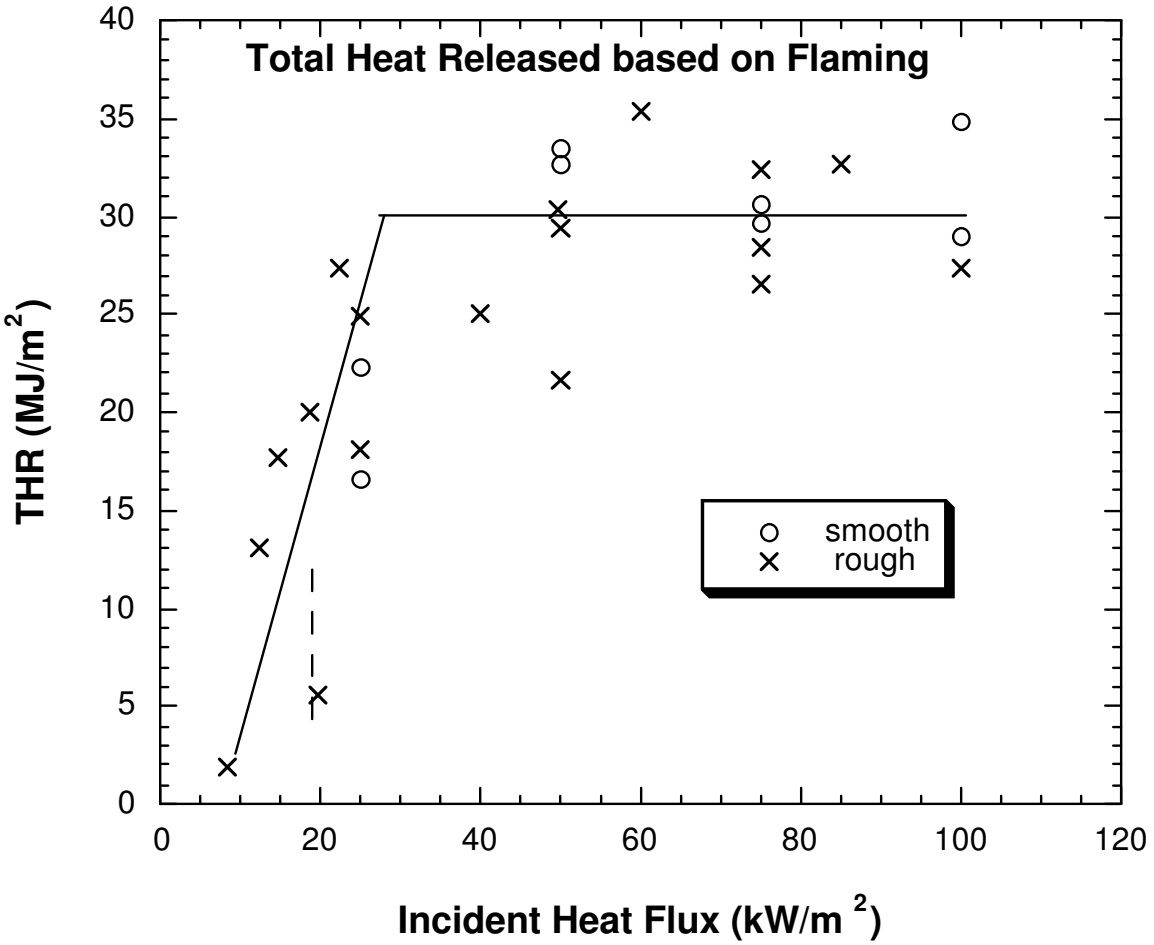


Burning in OSU Calorimeter

QuickTime™ and a
TIFF (Uncompressed) decompressor
are needed to see this picture.

Jet-like
flames

Overall Burning

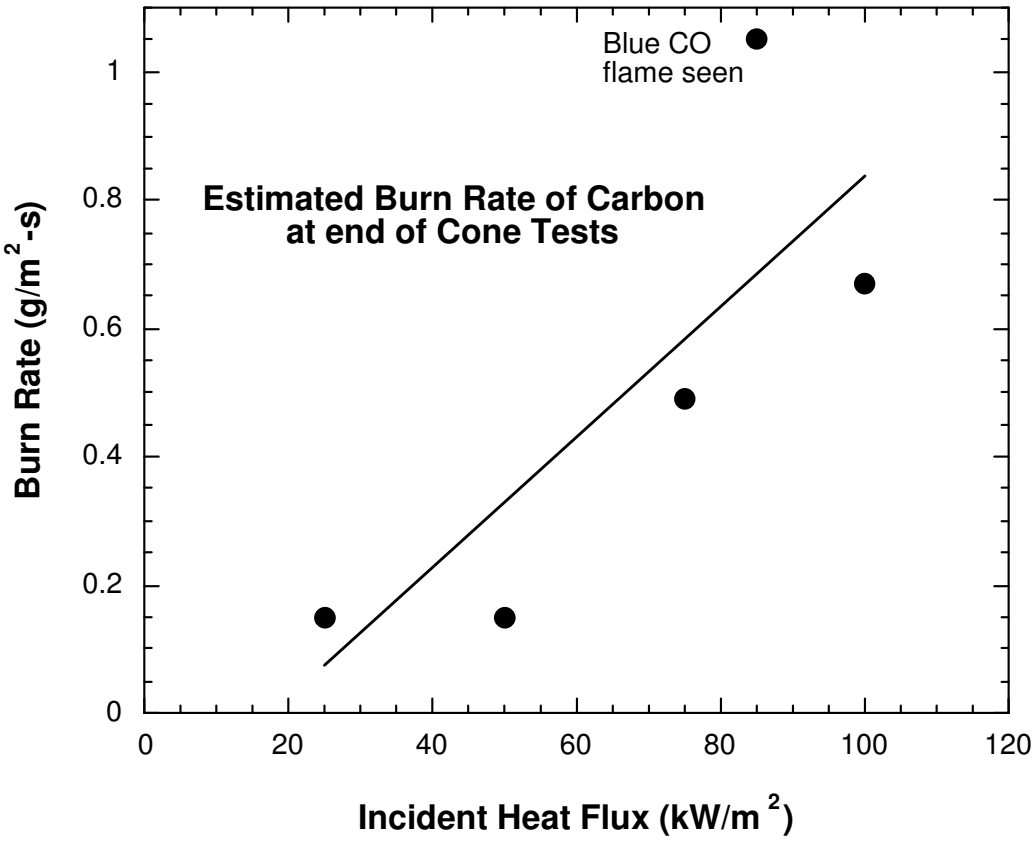


CHF (pilot ignition) ~ 18 kW/m^2

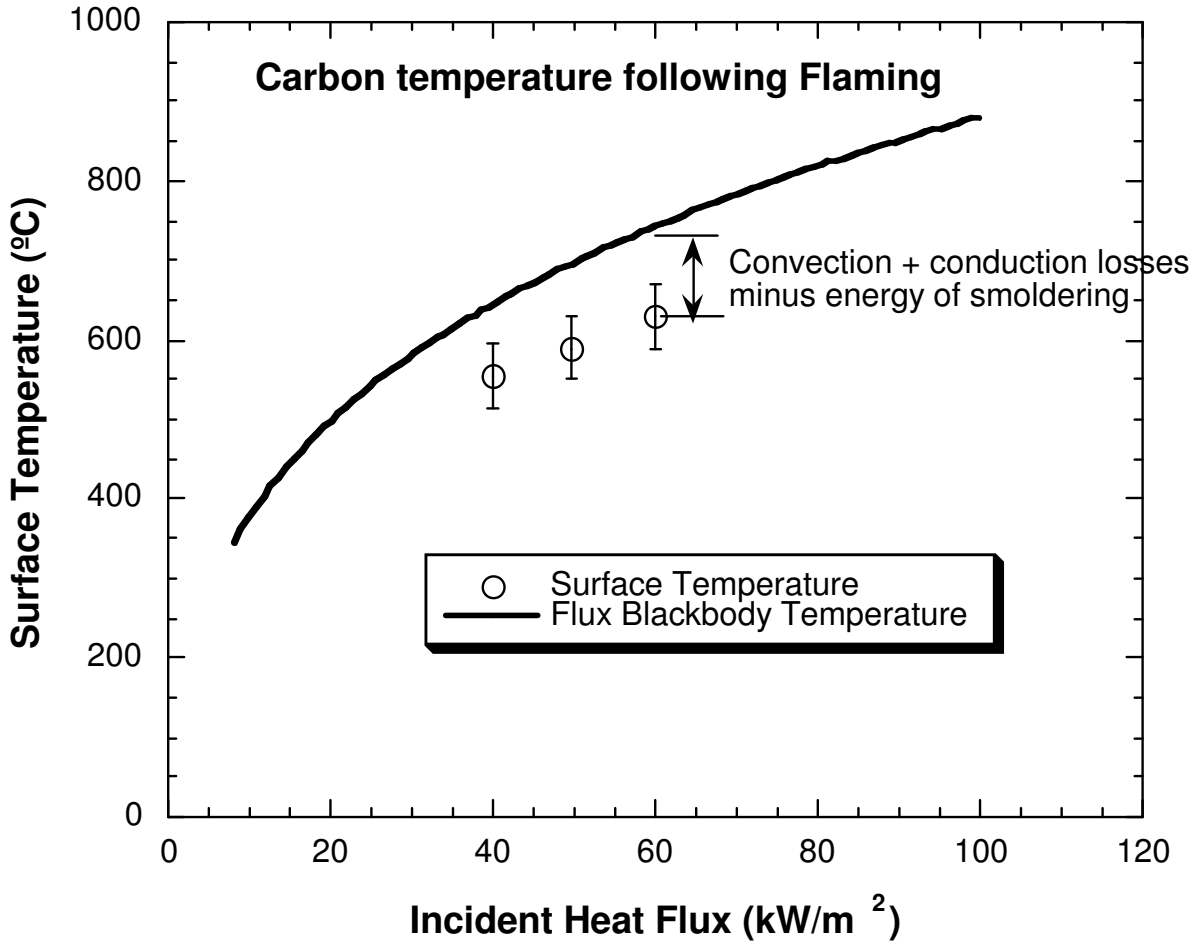
But can continue flaming to ~ 8 kW/m^2

Smoldering

- After flaming, smoldering can continue
- Blue flame also possible
- Energy rate ~ 5 – 35 kW/m^2



Temperatures in smoldering



Morphology of residue

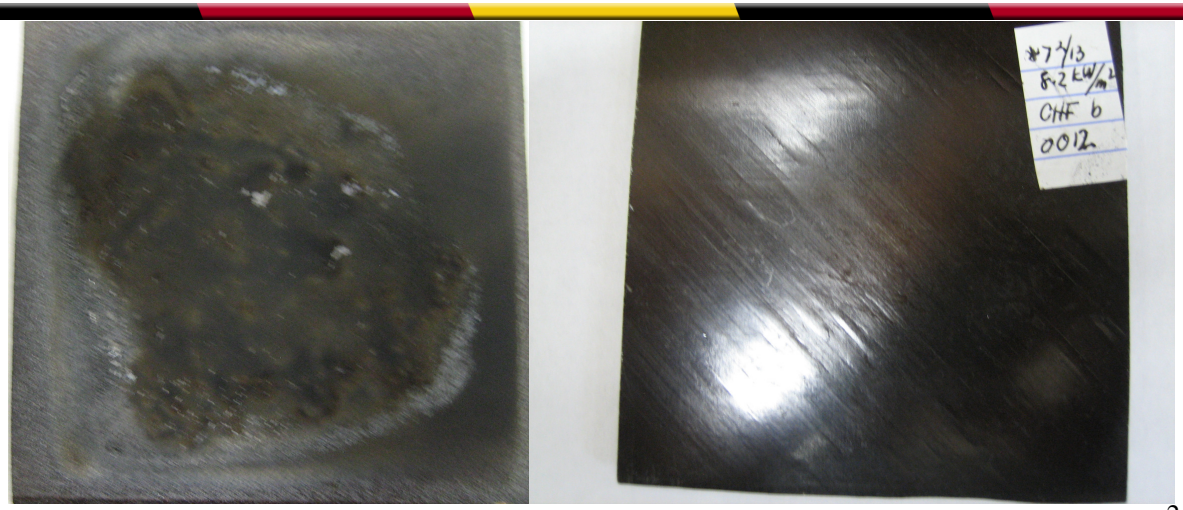


FIGURE 19A. AFTER BURNING FRONT AND BACK, 8.2 kW/m^2

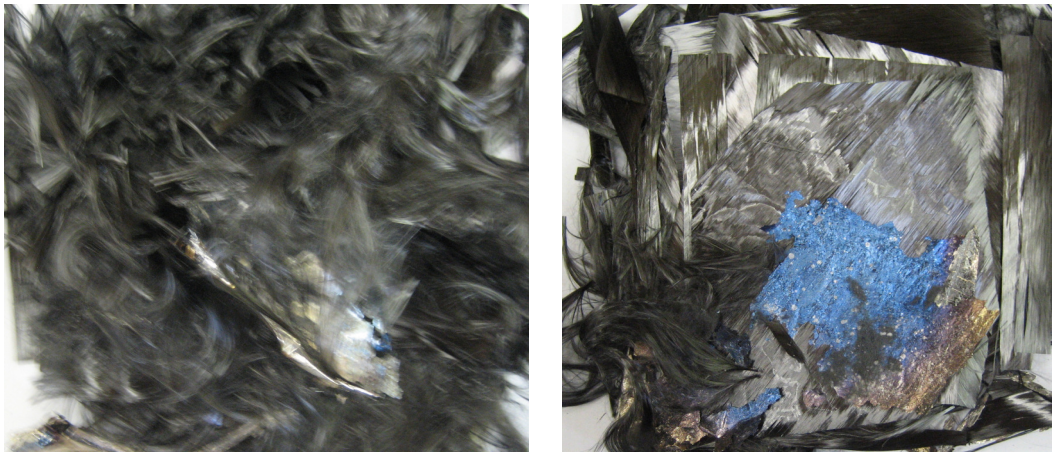
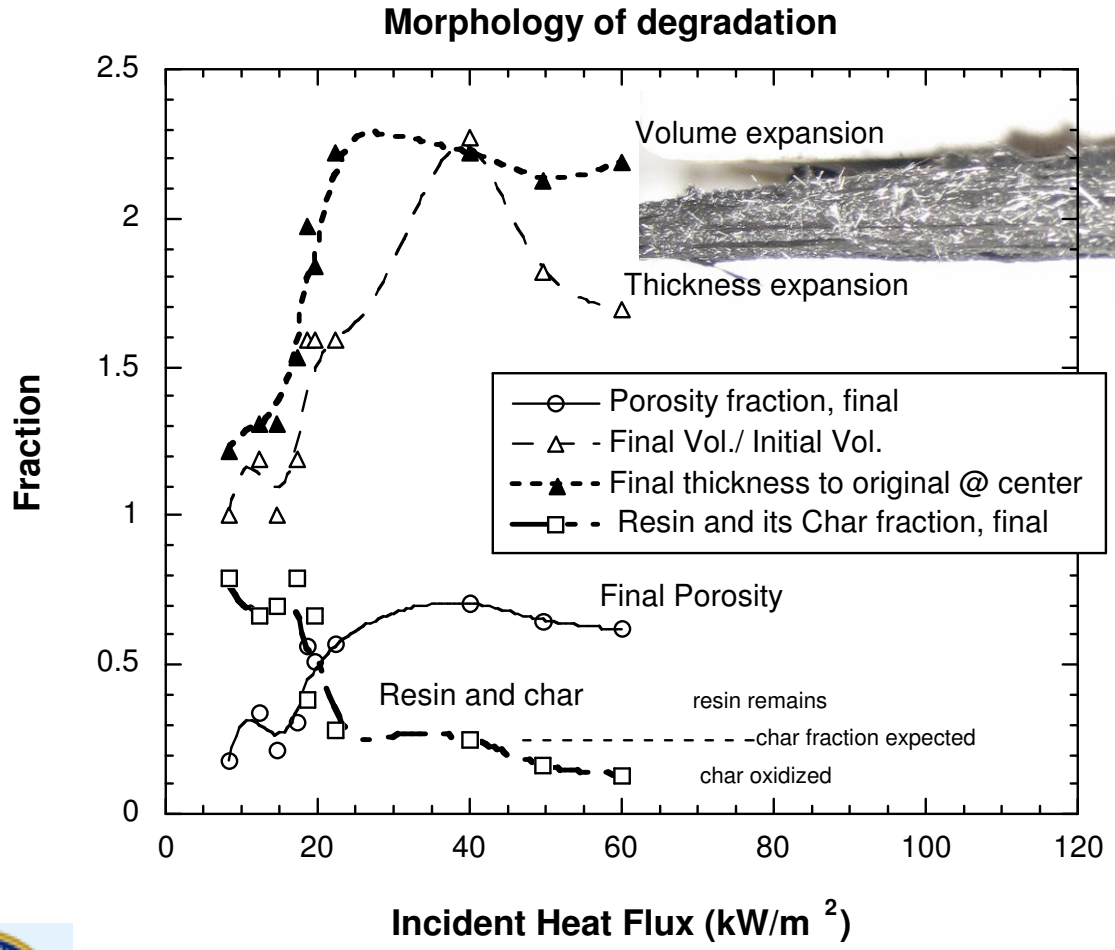


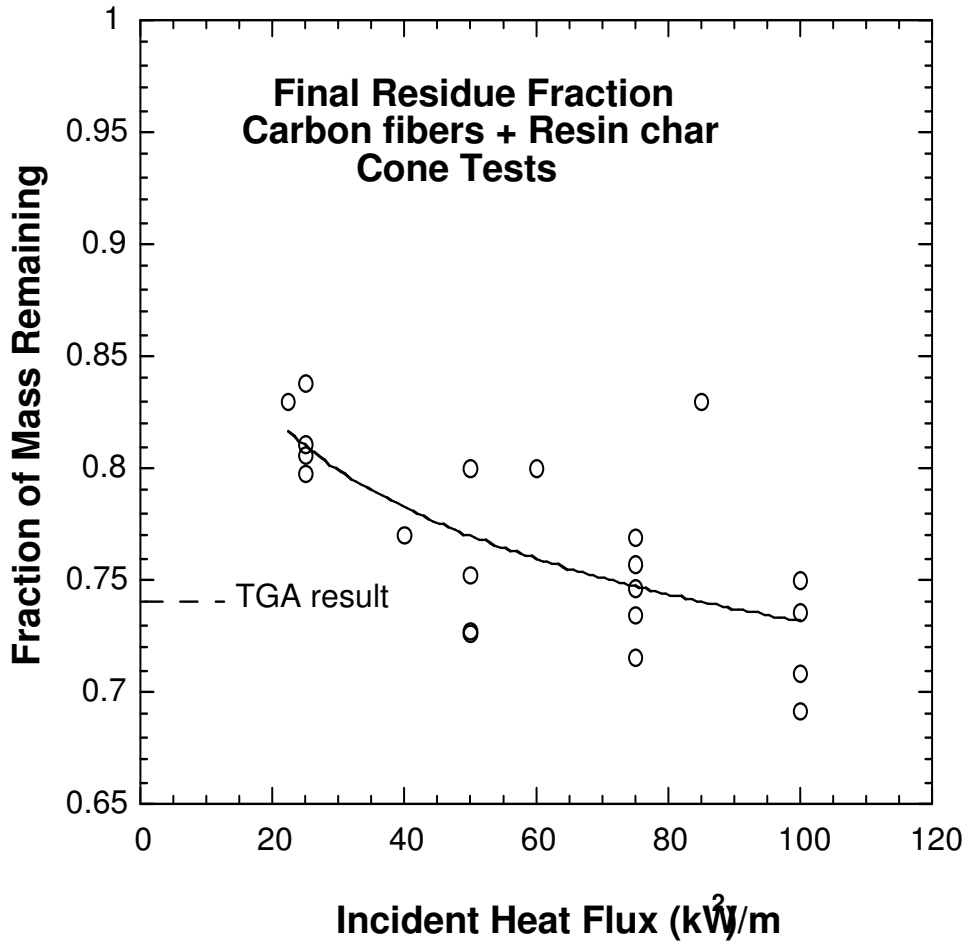
FIGURE 19F. AFTER BURNING FRONT AND BACK, 85 kW/m^2

Morphology properties



Char fraction of Resin ~ 0.25

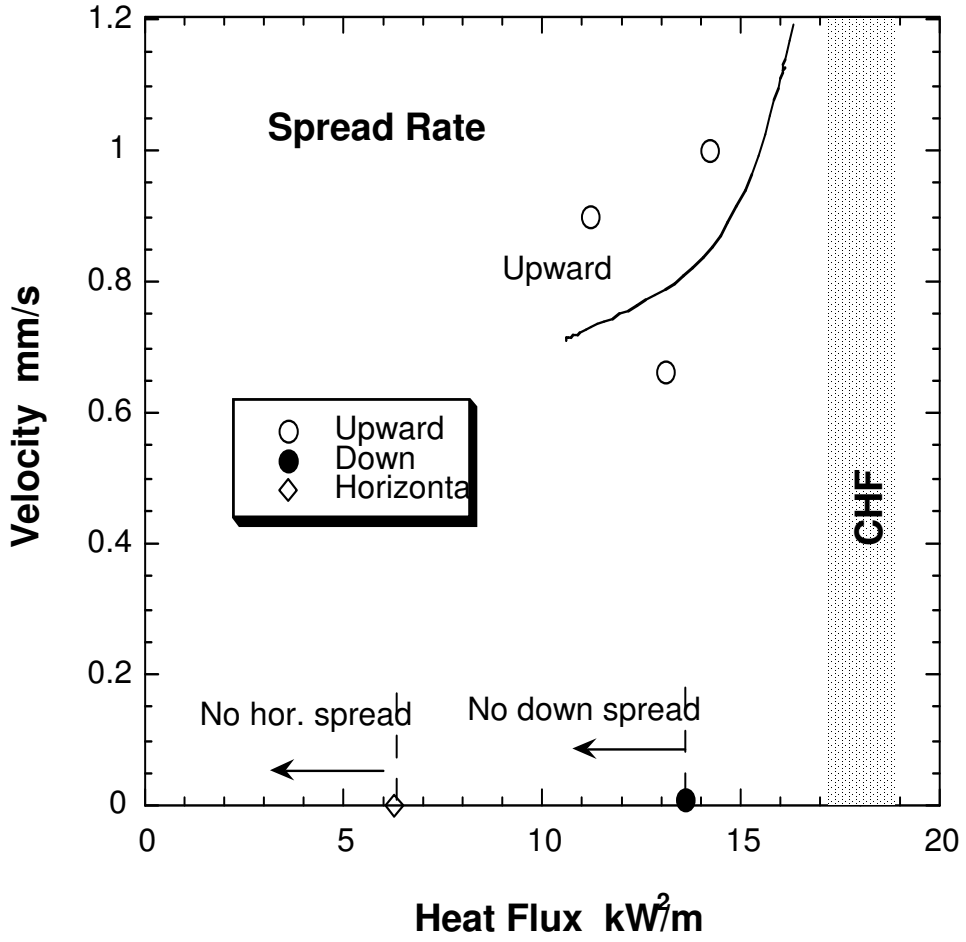
Residue Fraction: carbon+



Flame Spread

QuickTime™ and a
TIFF (Uncompressed) decompressor
are needed to see this picture.

Flame Spread Results



Concluding Remarks

- Properties determined for predicting hazards
- The sample can swell to over twice its volume, and its porosity after burning is about 65 %.
- The minimum heat flux required
  - for auto-ignition is 32 kW/m^2,
  - for piloted is 18 kW/m^2, and
  - for burning is about 10 kW/m^2.
  - Flame spread will occur for heat fluxes below 18 kW/m^2 after pre-heating for 4 minutes
- The remaining carbon fiber can smolder

End