Fire Performance as a Function of Incident Heat Flux

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Motivation

- Standard regulatory fire tests generally do not provide a complete picture of a material's fire performance
- Ignition resistance vs. fire performance
- Knowledge of fire performance useful in fire investigations
- Large number of standard test methods instead of a comprehensive testing methodology

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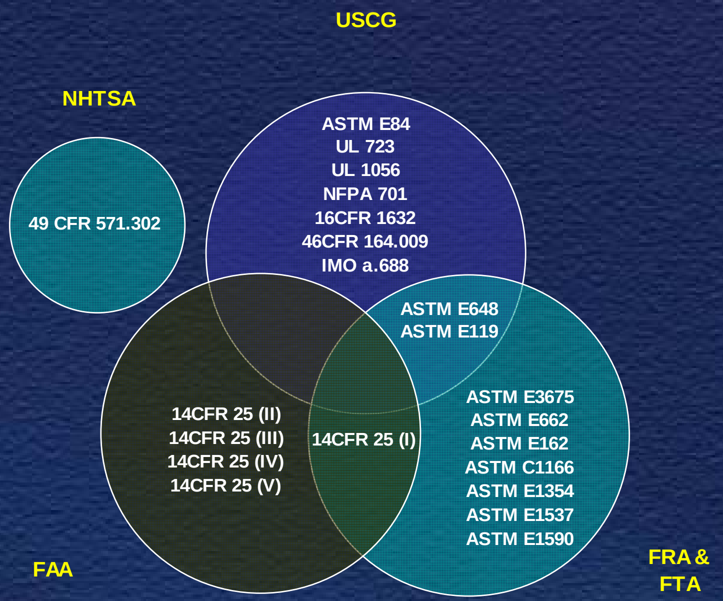
Flammability testing in the DOT

- There are numerous small & large scale standard test methods.
- There is diversity in their applicability and requirements.
- Classifications and Indexes



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Fire Performance

In the beginning stages of a fire the most influential parameter is the incident heat flux.

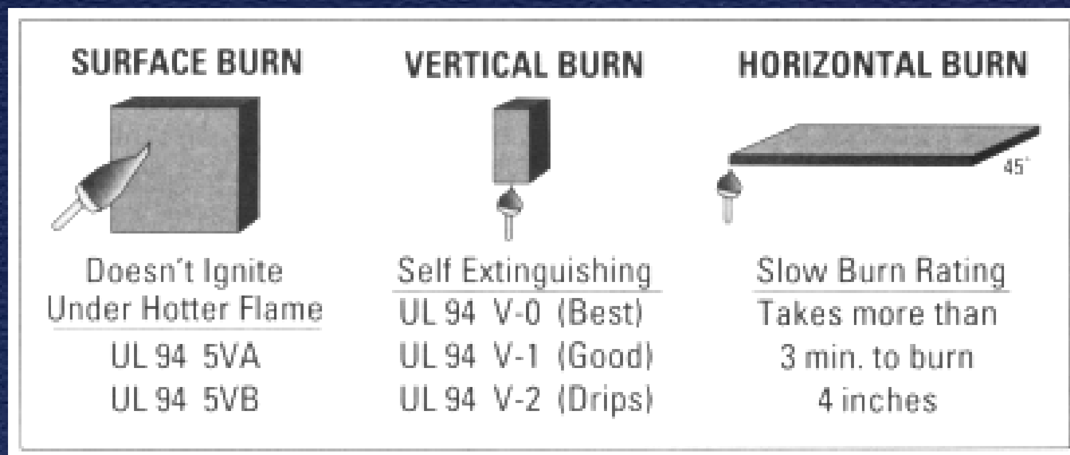
- Time to ignition (piloted & auto)
- Flame spread rate
- Burning rate

It seems logical that a framework for flammability testing should be a function of heat flux. This way a general overview of a material's fire performance can be drawn.

- "flammability diagram"

Bunsen Burner Type Tests

- Vertical horizontal or inclined flame spread test inside a draft proof chamber with a Bunsen burner ignition source



- Most common standard test method with many variants. (NHTSA, NASA, FAA)

Testing Framework

Calorimeter tests:
- Time to Ignition
- Peak Energy Release Rate
- Critical Heat Flux for Ignition (auto/piloted)

Flame Spread tests:
- Upward & Downward flame spread velocity

Additional Parameters:
- Mass Flux at ignition
- Minimum heat flux for sustained burning

Materials

Aircraft Sandwich panel
Polyphenylene sulfide [PPS]
Polyvinyl chloride [PVC]
Polyamide 6,6 [PA66]
High-Impact Polystyrene [HIPS]
High-Density Polyethylene [HDPE]
Polyvinylidene fluoride [PVDF]
Polyoxymethylene [POM]
Polycarbonate [PC]
Poly(methyl methacrylate) [PMMA]
Acrylonitrile butadiene styrene [ABS]
Polyetherimide [PEI]

- Thermoplastics

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Flame Spread Apparatus

Propane fueled radiant heaters.

0 – 17 kW/m^2

Uniform heat flux along sample surface

Fixed Alignment

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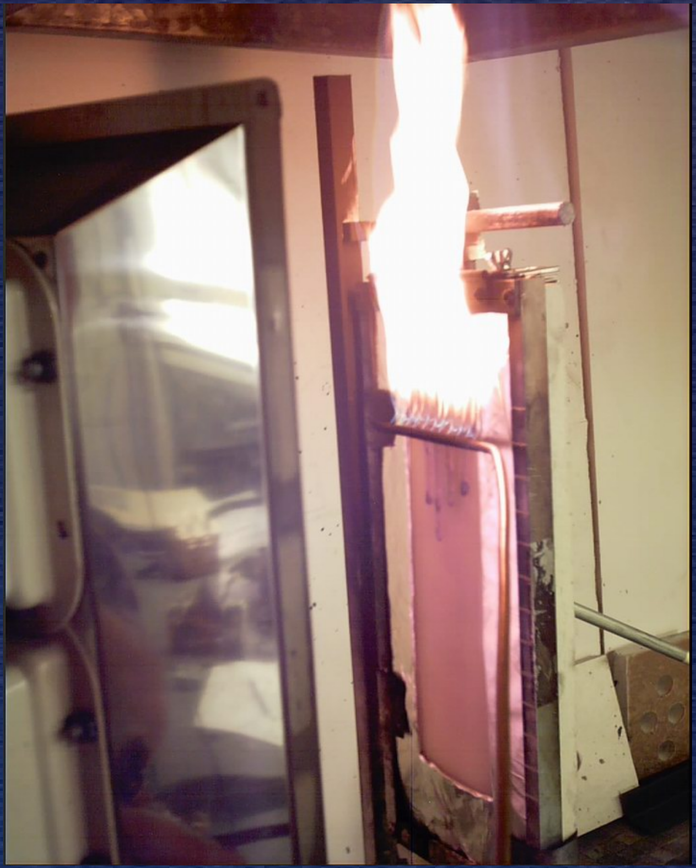
Flame Spread Apparatus

- Sample dimensions:

  3”W x 12”L

- Insulated backing

- Uniform ignition along sample face



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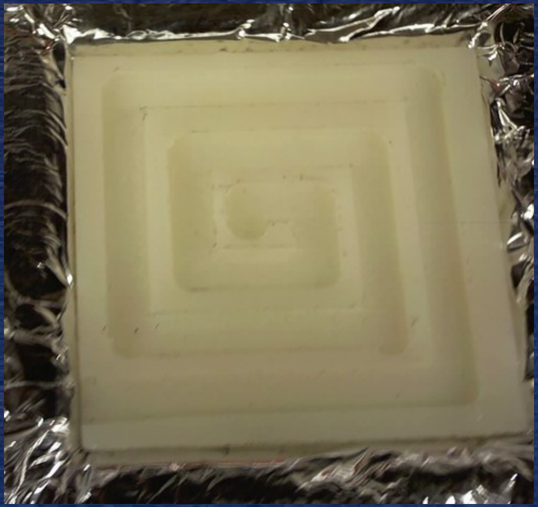
Cone Calorimeter

- Rebuilt Atlas II Calorimeter
- All original circuitry was removed
- Essential systems maintained (cold trap, cone heater, exhaust fan)
- Essential sensors maintained (load cell, thermocouples, Oxygen, differential pressure and heat flux)
- LabView® user interface

Sample Behavior in The Cone

- Deformation/buckling (PEI, PVC)
- Skin over surface (Nylon)
- Temporary ignitions (PVDF, PEI, PVC)



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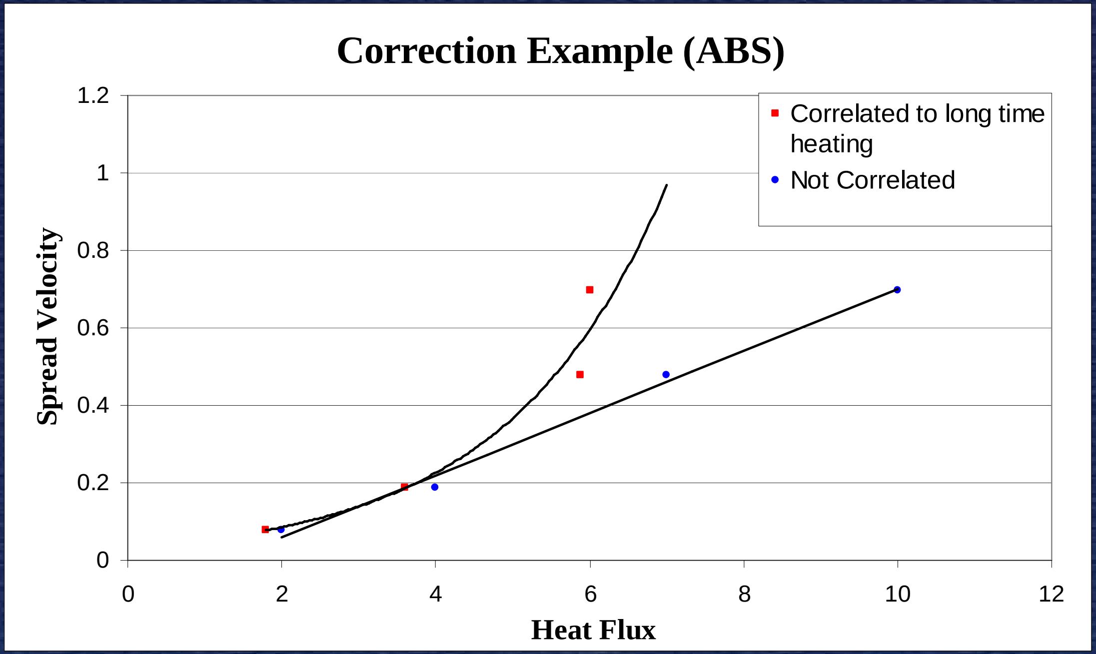
Sample Behavior during Flame Spread

•Deformation before reaching steady state (ALL)

•Melting/Dripping (HDPE, POM, PMMA)

•"Sooting" (HIPS, ABS)

Correction for reduced preheating



Find thermal response time of a material F(t) from ignition data.

Correct for shortened preheating time by adjusting the incident heat flux with F(t) as done in the ASTM 'LIFT' test

$$\dot{q}'' = \dot{q}''_{\infty} F(t)$$

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Additional Fire Properties

Mass flux at ignition:

- Take derivative of mass loss signal at point of ignition
  - Heating rate
  - Igniter position

Minimum Heat Flux for Sustained burning:

- Preheat with a heat flux < critical
- Force ignition
- Adjust heater temperature until fire decays after forced ignition (may need to repeat a few times)

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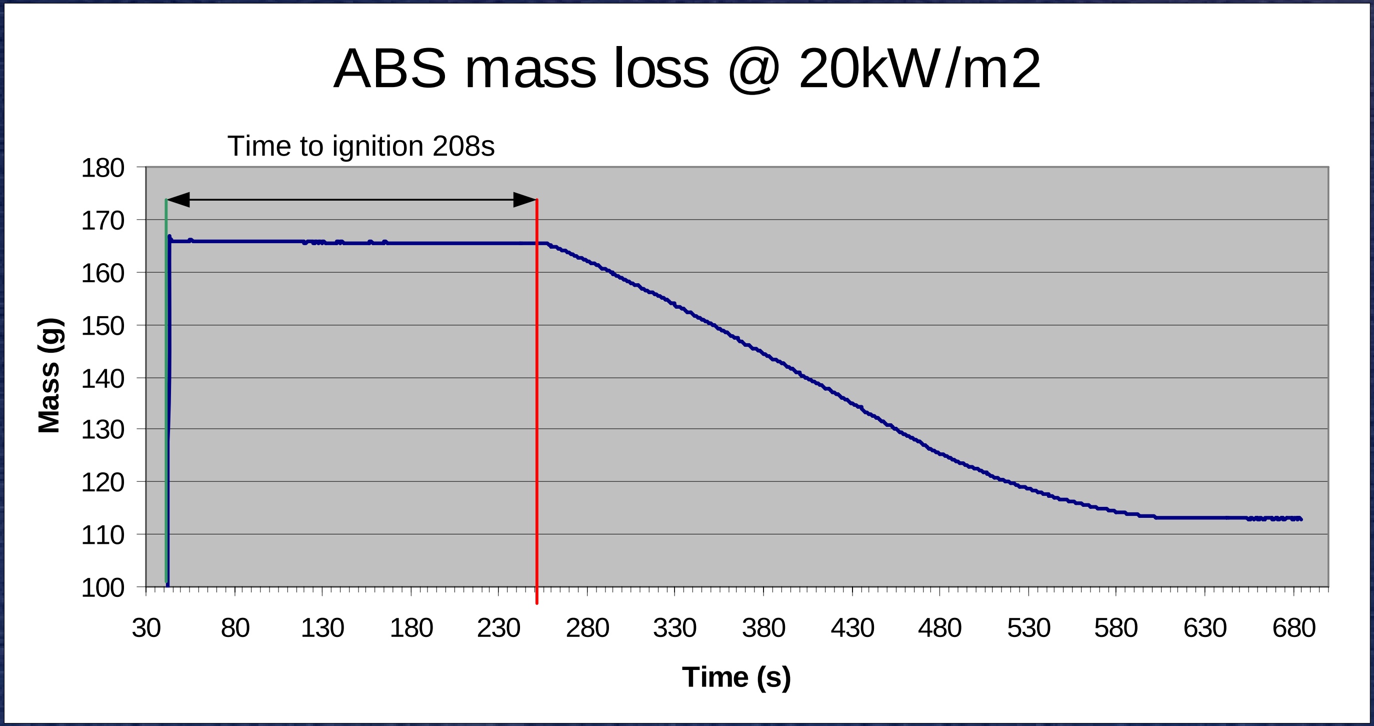
Minimum Heat Flux for Sustained Burning

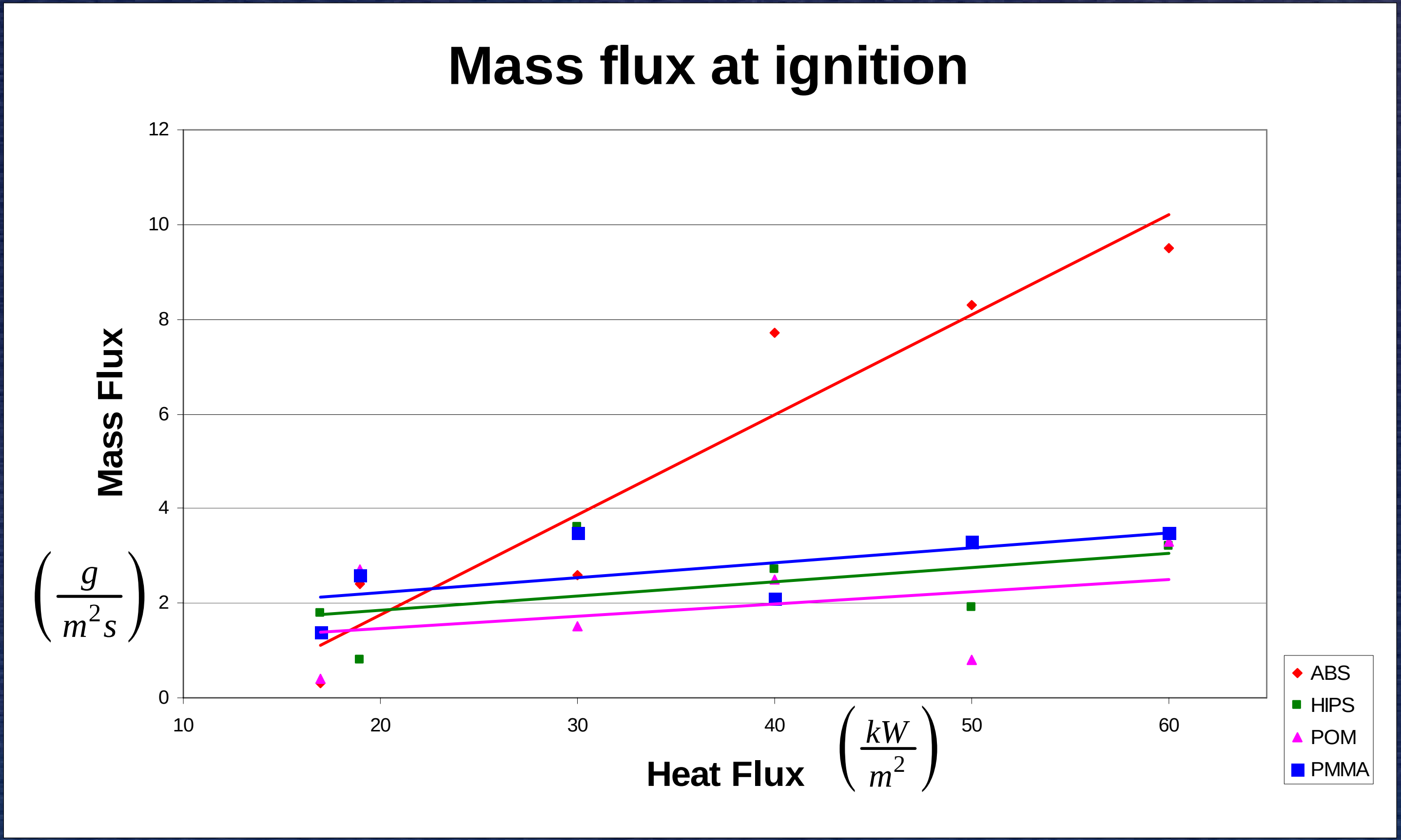
Material	Critical Heat flux for ignition (kW/m2)	Minimum Heat Flux for Sustained Burning (kW/m2)
Polyamide 6,6 [PA66]	18	3.5
High-Impact Polystyrene [HIPS]	16	0
High-Density Polyethylene [HDPE]	16	0
Ployvinylidene fluoride [PVDF]	38	38
Polyoxymethylene [POM]	8	0
Polycarbonate [PC]	28	12
Poly(methyl methacrylate) [PMMA]	8	0
Acrylonitrile butadiene styrene [ABS]	12	0

Mass Flux at ignition



It is often necessary to go back 5 sec from measured ignition time to get results that are consistent with literature values.

Mass Flux at ignition



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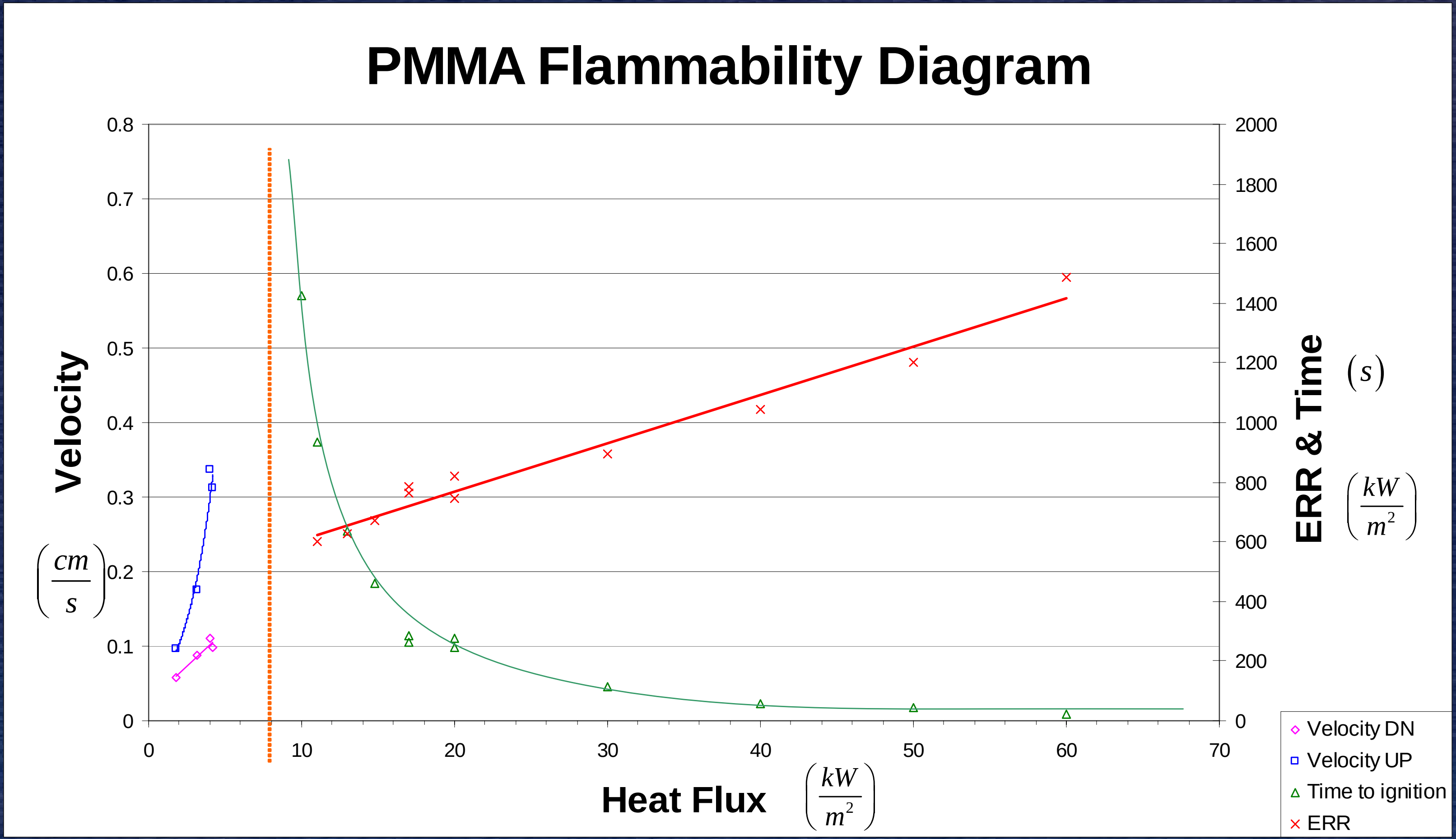
Flammability Diagrams



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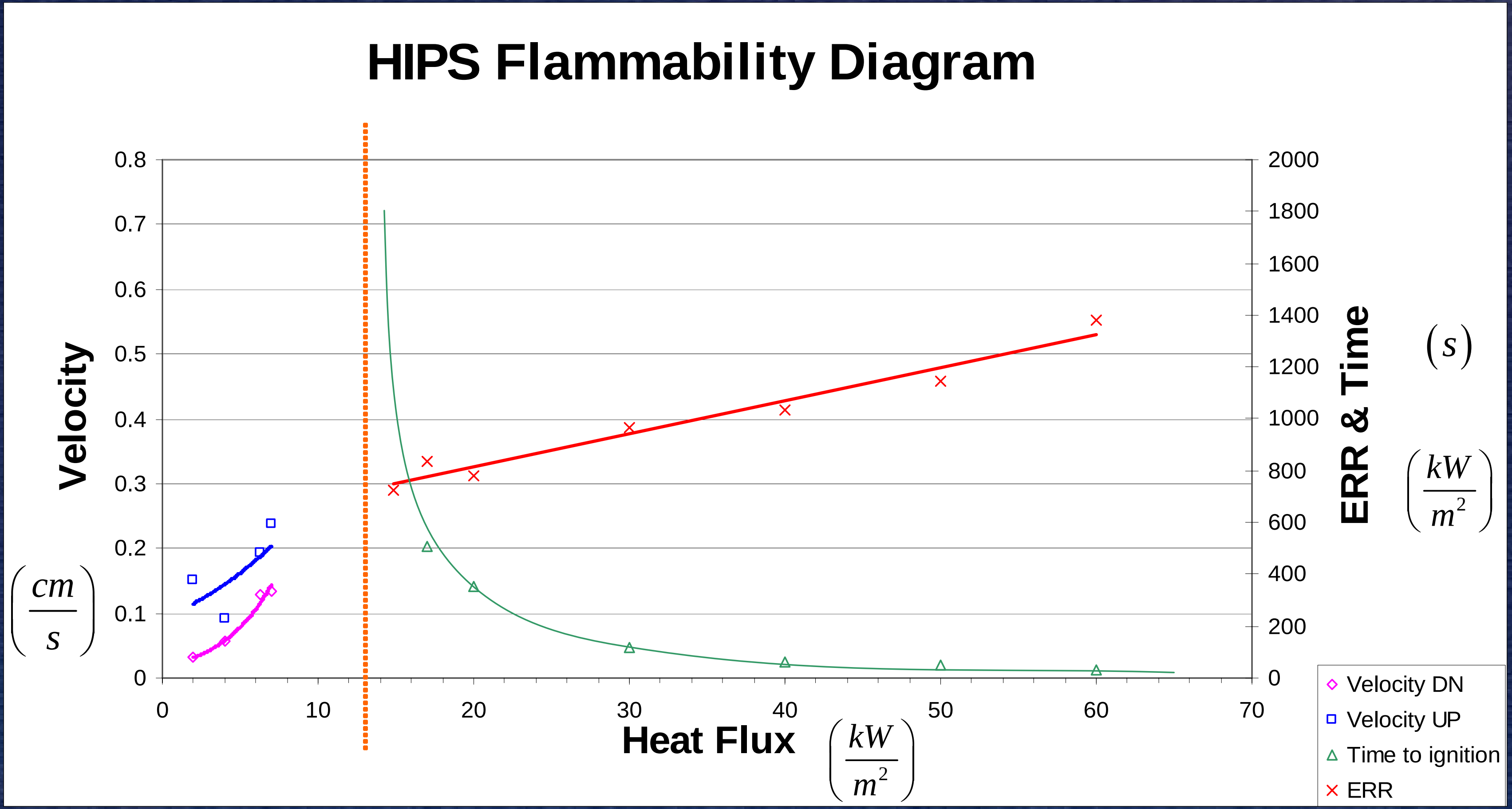
Flammability Diagrams



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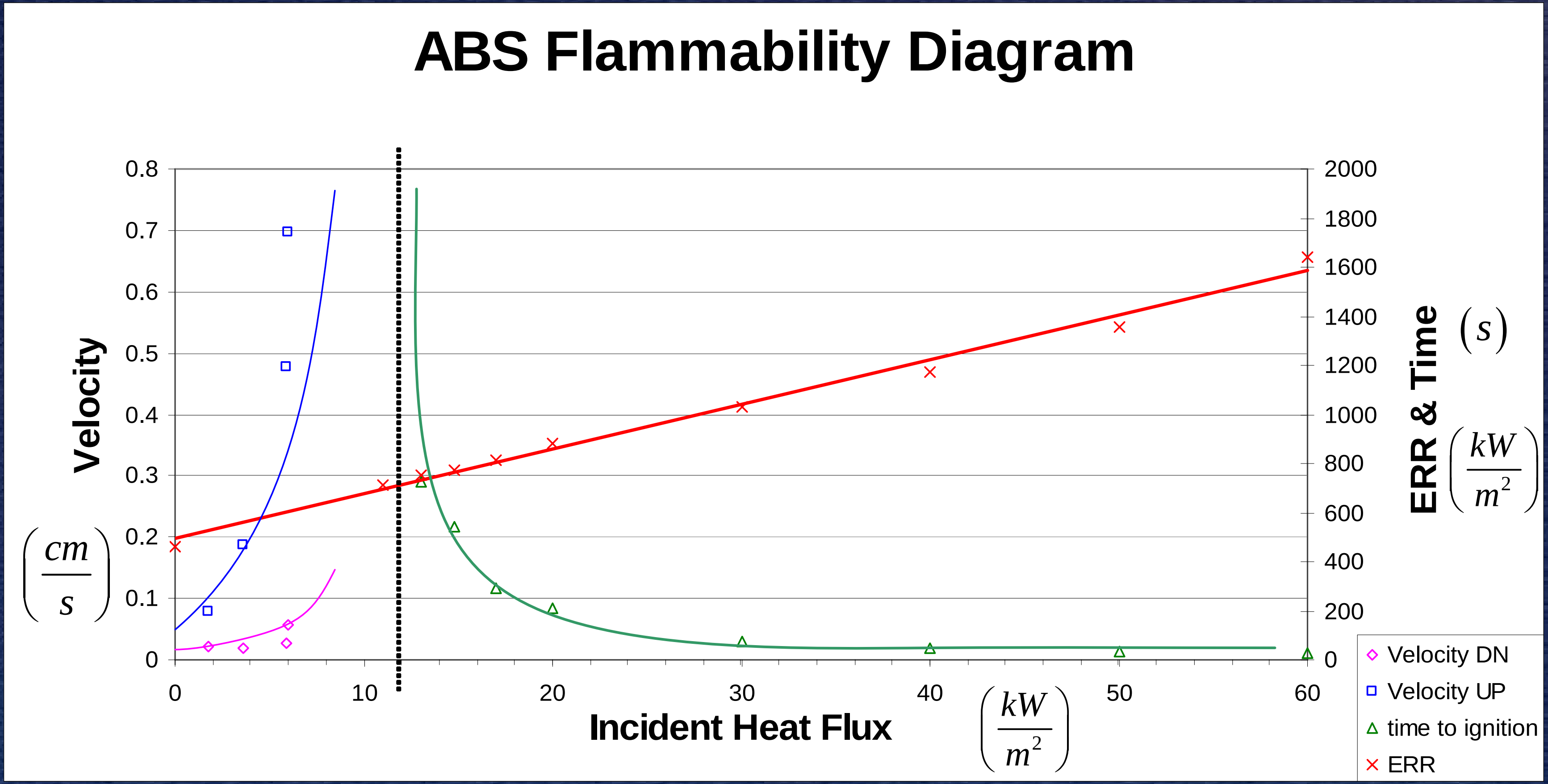
Flammability Diagrams



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Conclusions

- Meaningful flammability diagrams can be drawn for most materials despite difficulties such as melting/dripping etc.
- Other testing configurations may be necessary to compensate for material behavior
- Flammability diagrams provide a complete picture of a materials behavior in fire conditions.

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