Forty years of Material flammability: An appraisal of its role, its experimental determination and its modelling prediction

Dr Nicolas BAL – Risk Quantification Engineer

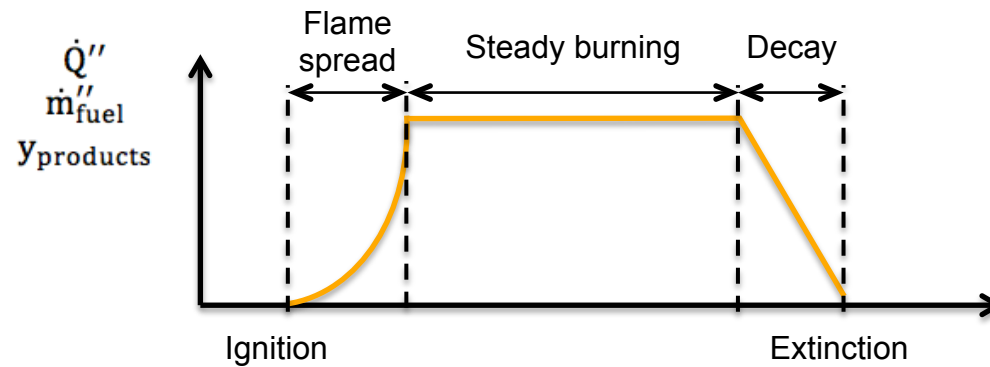University of Edinburgh – 15th of May 2014

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What is material flammability?

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What is material flammability?

The curve shows $\dot{Q}''$, $\dot{m}''_{fuel}$, $y_{products}$ versus time with regions labelled: Ignition, Flame spread, Steady burning, Decay, Extinction.

The Dalmarnock Fire Tests: Experiments and Modelling,
G. Rein, C Abecassis Empis, R. Carvel, School of Engineering and Electronics, University of Edinburgh (2007)

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What is material flammability?

- **Material flammability *CANNOT* be expressed by a single quantifiable property.**

- **The definition of the fire properties evolves with the mathematical representation.**

Energy
Fuel

Mathematical representation

Complexity ∞
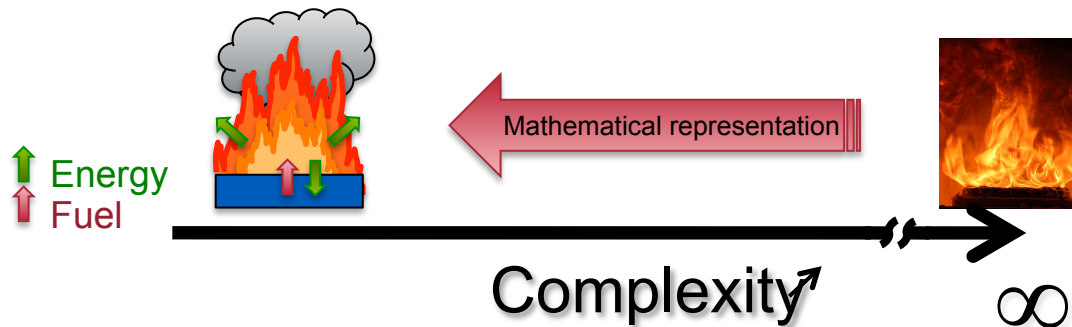
A set of fire properties is required.

Ignition	
T_{ign}	Surface temperature at ignition
$k\rho c$	Apparent thermal inertia
$\dot{q}''_{critical}$	Critical heat flux for ignition

Flame spread	
T_{ign}	Surface temperature at ignition
$k\rho c$	Apparent thermal inertia
ϕ	Flame spread parameter

Burning and heat release rates	
$\Delta H_c / \Delta H_g$	Heat release rate parameter or combustibility ratio

Smoke and toxic component production rate	
y_i	Specie yield

Understanding Materials Flammability,
C. Lautenberger, J.L. Torero and A.C. Fernandez-Pello, in:
Flammability Testing of Materials Used in Construction,
Transport and Mining, Woodhead Publishing (2006)

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Material flammability approaches in FSE strategy

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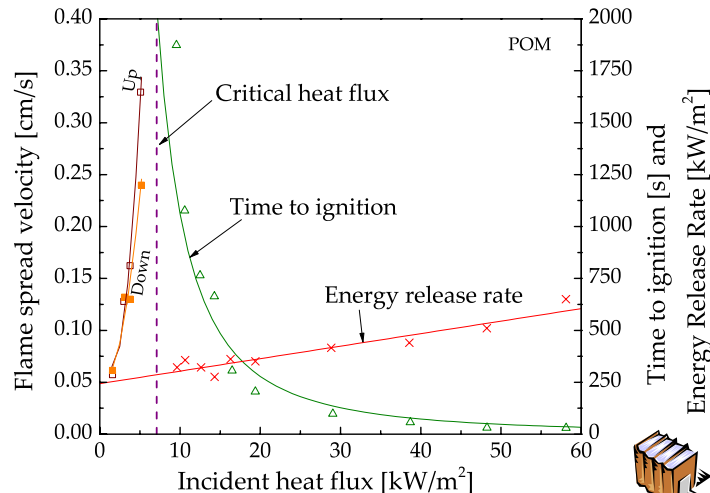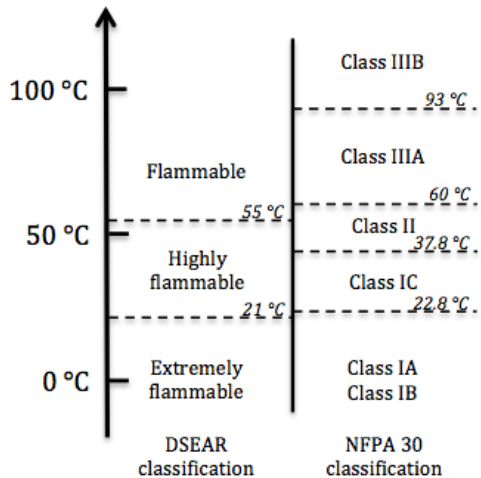# Material flammability approaches in FSE strategy

Ranking-based approach

- **Hypothesis:**
  - All the material located in an enclosure will be eventually engulfed in the fire.

- **Ranking of the materials according to their fire behaviour: fire classes**
  - Classification according performance criteria (fail/pass test) or quantitative measurements.

A theoretical basis for flammability properties,
J.G. Quintiere, Fire and Materials (2006)

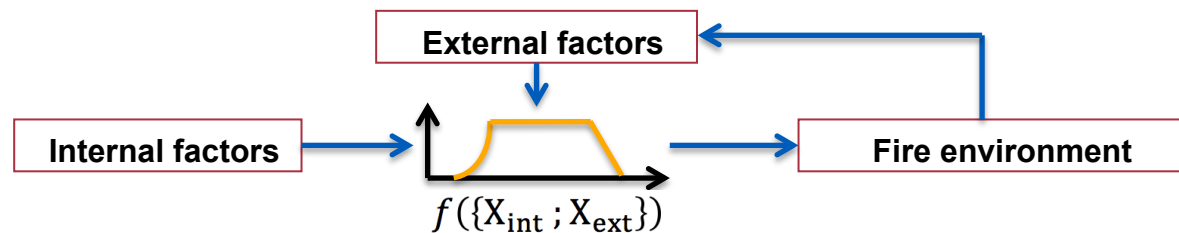**Advantages:** easy to perform and product specific.

Drawbacks: discrepancies in ranking scales and no assessment of the global fire safety level.

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Material flammability approaches in FSE strategy

Comprehensive approach

- **Hypothesis:**
  - Coupling between the material fire behaviour and the fire environment is predominant.

- **Characterization of the physico-chemical response to an external heat stress.**
  - Use of pyrolysis model more or less sophisticated.

*"Since there is an **endless number of polymer products** having different molecular weights and additives (often not described in the commercial products), it is essentially **impossible to measure all** necessary physical and chemical **characteristics** for each of these products in an attempt to predict flammability characteristics"*

Dr Takashi Kashiwagi

Polymer combustion and flammability – Role of the condensed phase,
T. Kashiwagi, Proceedings of the symposium (international) on combustion 25 (1994)

Advantage: Quantification of fire behaviour based on its environment.

Drawbacks: Inability to measure all parameters and dependency to pyrolysis model.

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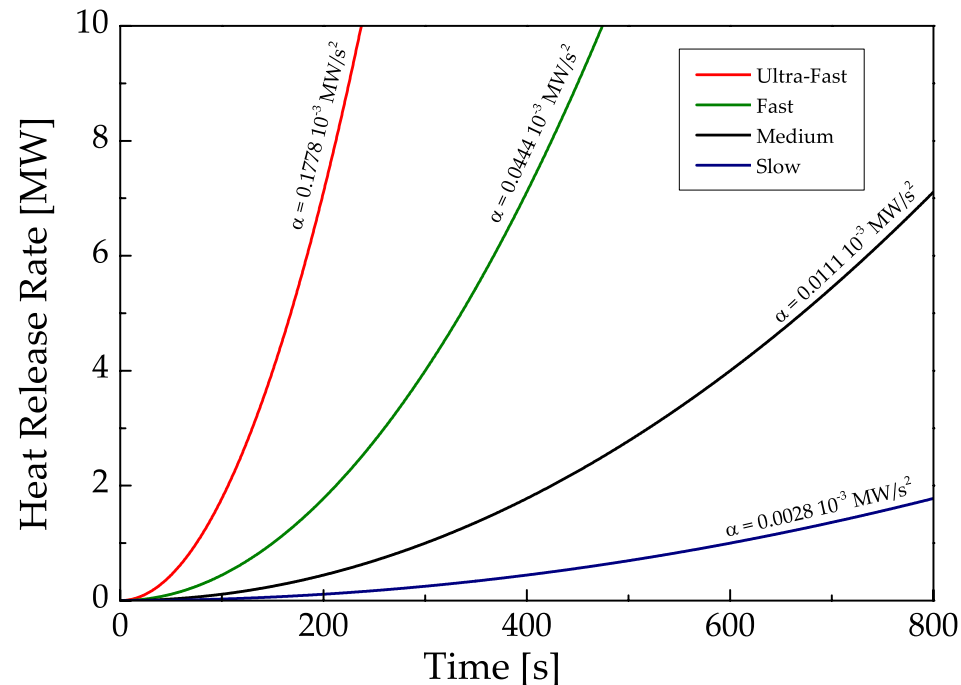# Material flammability approaches in FSE strategy

Semi-comprehensive approach

- **Hypothesis:**
  - The fire behaviour and its interaction with its environment can be assumed a priori.

- **Prescription of the fire based on type of building and activities.**
  - Design fire scenarios

- **Infinite number of scenarios.**

Advantage: Overcome in part issues from ranking-based and comprehensive approaches.

Drawbacks: Only a relative safety factor can be established and large modelling uncertainties.
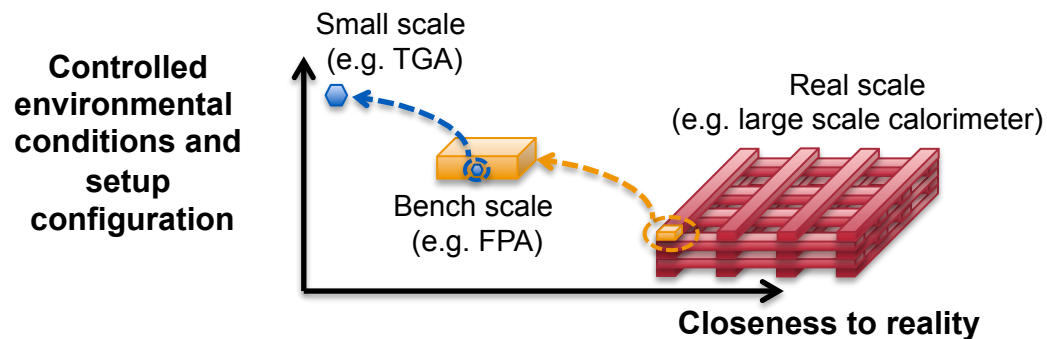
Measurement of material flammability

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Measurement of material flammability

Scaling influence

- **Fire property extraction may require small and bench scale experiments.**

- **Advantages:**
  - Better control of external factors and uniformity of intensive properties (*e.g.* Temperature).

- **Drawbacks:**
  - Material not tested in its end-use configurations and in real fire conditions.
 - Governing mechanisms may change with the scale.

Controlled environmental conditions and setup configuration

Small scale (e.g. TGA)

Bench scale (e.g. FPA)

Real scale (e.g. large scale calorimeter)

Closeness to reality

Scaling down phenomena is required to extract some fire properties but implies also some issues regarding its representativeness.
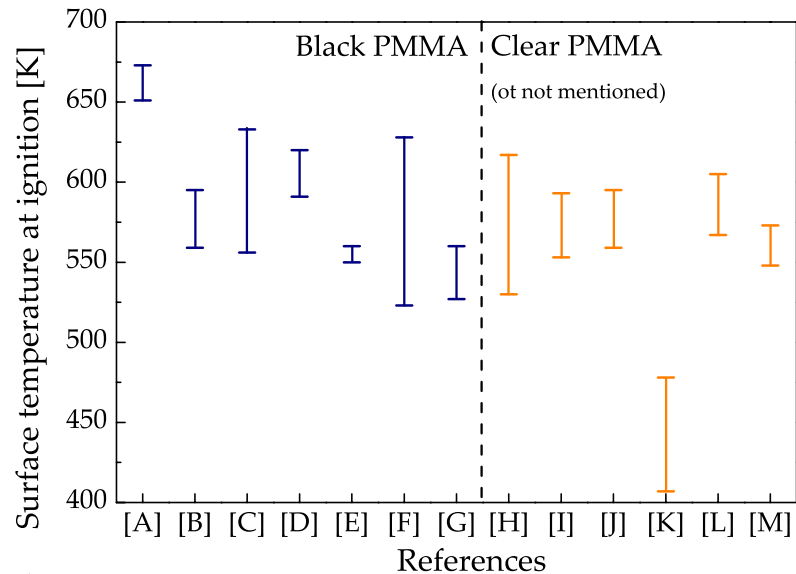
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Measurement of material flammability

Environmental conditions and setup configuration influence

- **Experimental procedures fixed external factors.**
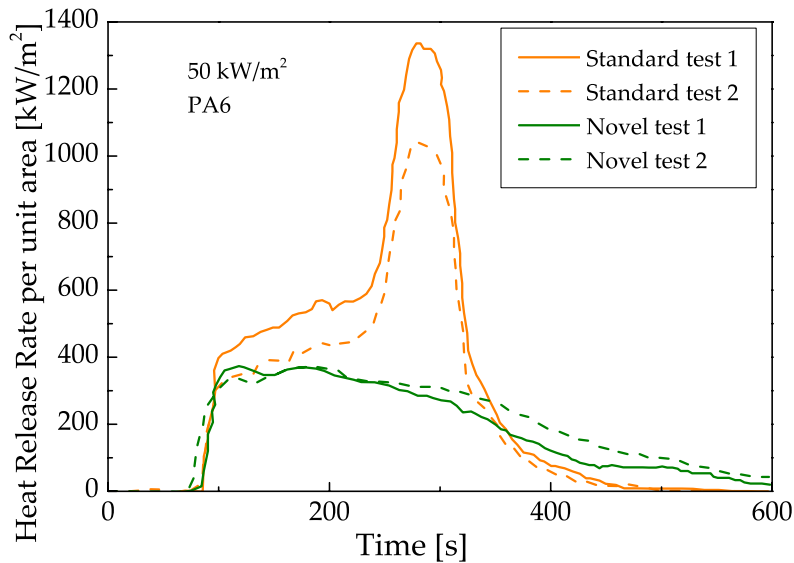
Determination of the flammability properties of polymeric materials: A novel method
R. Carvel, T. Steinhaus, G. Rein and J.L. Torero,
Polymer Degradation and Stability (2010)

Uncertainty and complexity in pyrolysis modelling,
N. Bal, Phd dissertation (2012)

Material fire behaviour and extracted fire properties are strongly sensitive to external factors evolution.
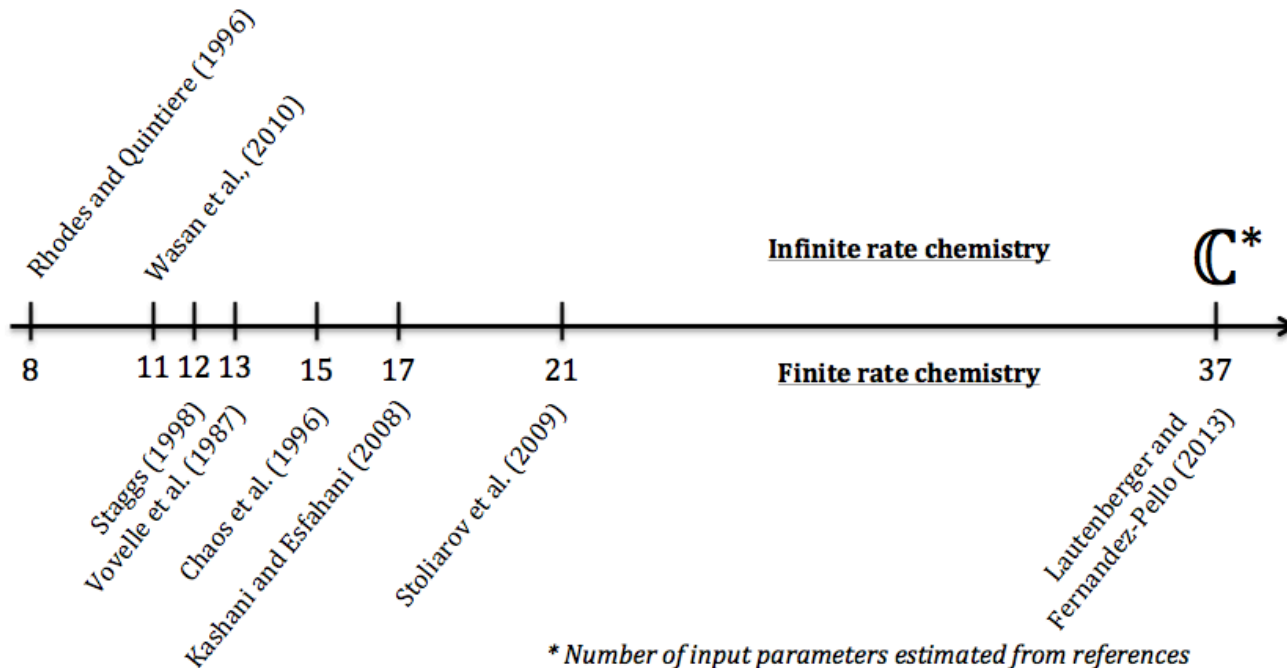
Modelling of material flammability

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Measurement of material flammability

Model complexity

- **Main types: correlations / semi-empirical correlation / comprehensive model.**

- **Growing understanding enabled the introduction of more mechanisms.**

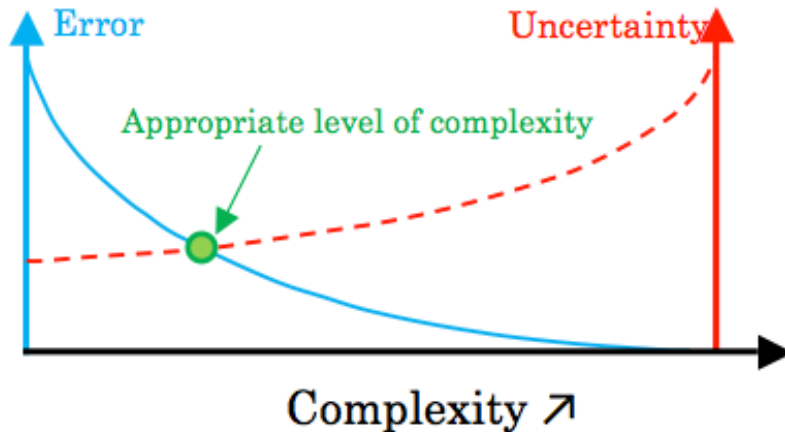* Number of input parameters estimated from references

The growing model complexity in pyrolysis model entrains an increase of the number of parameters that need to be calibrated.

Measurement of material flammability

Model calibration

- **Parameter uncertainty may overcome the global modelling error due to lack of mechanisms.**

"*It is common to reach the conclusion that complex models are not justified because unavoidable scenario uncertainties lead to output variations much larger than those associated to errors induced by the simplifications introduced in simple model*"

Prof José L. Torero

Uncertainty and complexity in pyrolysis modelling,
N. Bal, Phd dissertation (2012)

Scaling-up fires,
J. L. Torero, Proceedings of the symposium (international) on combustion 34 (2013)

The prediction of material fire behaviour from a simple model may be more useful than those from a complex model not calibrated.

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Concluding remarks

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Material flammability

Concluding remarks (OPEN TO DISCUSSIONS)

- **While different approaches exist to integer material flammability in FSE strategy, the future of FSE is pointed toward fire behaviour quantification.**

  "Combustibility of building materials, furnishings, and occupancy must be known before a rational evaluation of a structure's resistance to the development of a catastrophic fire can de made "

  Dr Edwin Smith

  An experimental determination of combustibility, E. Smith, Fire technology (1971)

- **Significant evolution of the global understanding in material flammability but still large uncertainty on the fire quantification for design purposes.**

- **Fire engineers and authority having jurisdiction should be aware that any conclusion on fire safety level is limited by this uncertainty.**

- **Sensitivity analyses to define governing parameters of design fire scenarios combined with uncertainty analyses (*e.g.* using Monte Carlo) seem to be the next path to grow in fire safety.**

  The uncertainty in material flammability should not (and cannot) prevent innovation and building construction but should be accepted as a risk in the current approaches.

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Thank you

While HRR is claimed to be the most important parameter in fire, its prediction is probably the most uncertain.

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