Microscale Combustion Calorimetry and Material Change Similarity.

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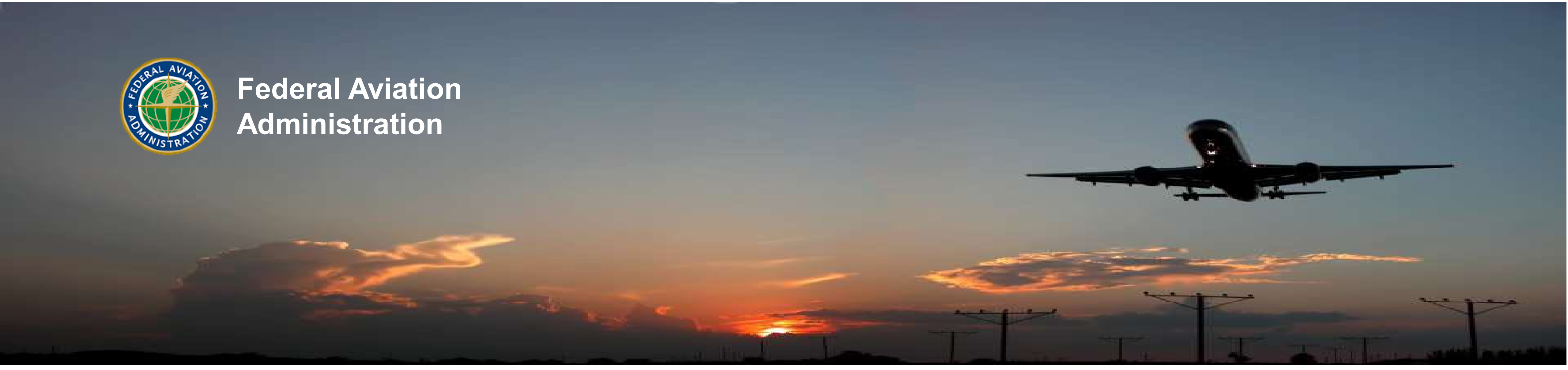


Outline

- Microscale combustion calorimetry (*MCC*) and Fire growth capacity (*FGC*)
- Comparison of *FGC* and FAA bench scale fire test results.
- *FGC* criterion for equivalent (similar) fire performance

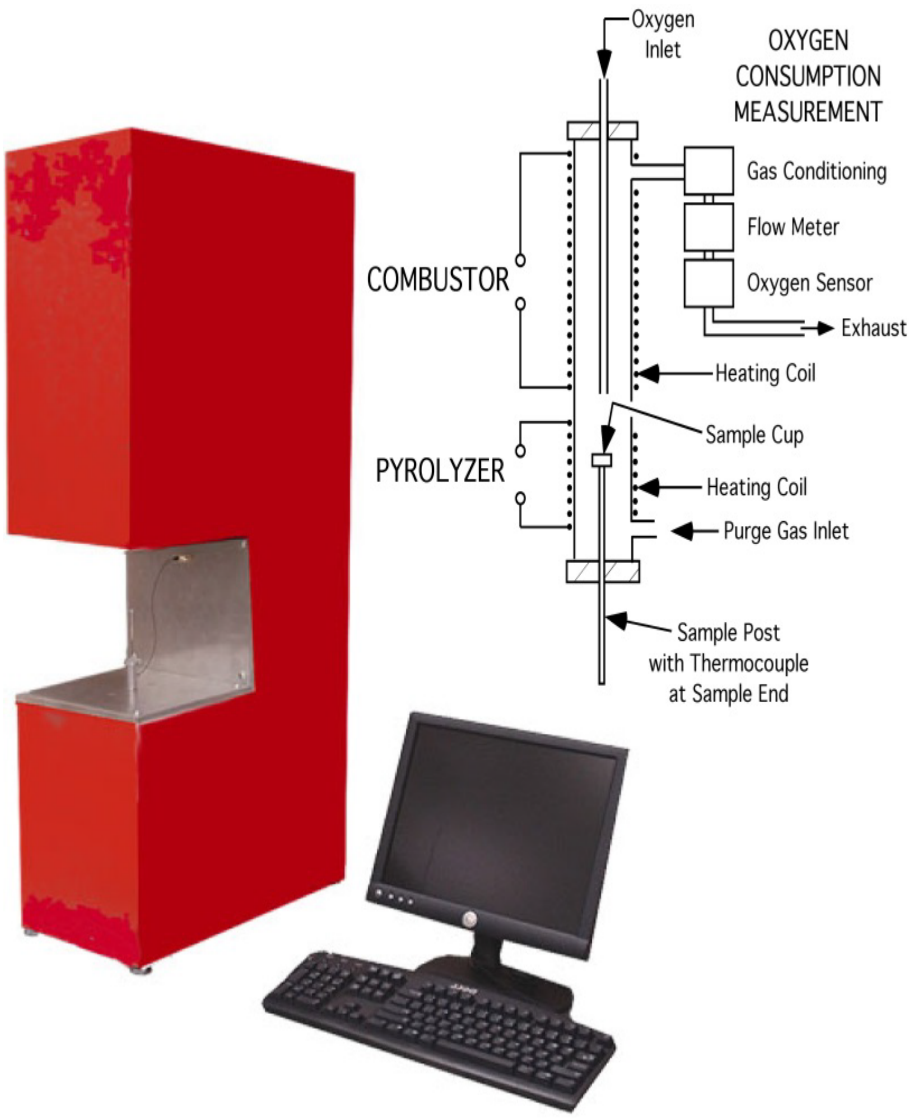
Microscale combustion properties and bench-scale fire tests

MCC uses well-defined samples and conditions that provide precise, repeatable and convenient measurements of intrinsic combustion properties of materials

BUT….

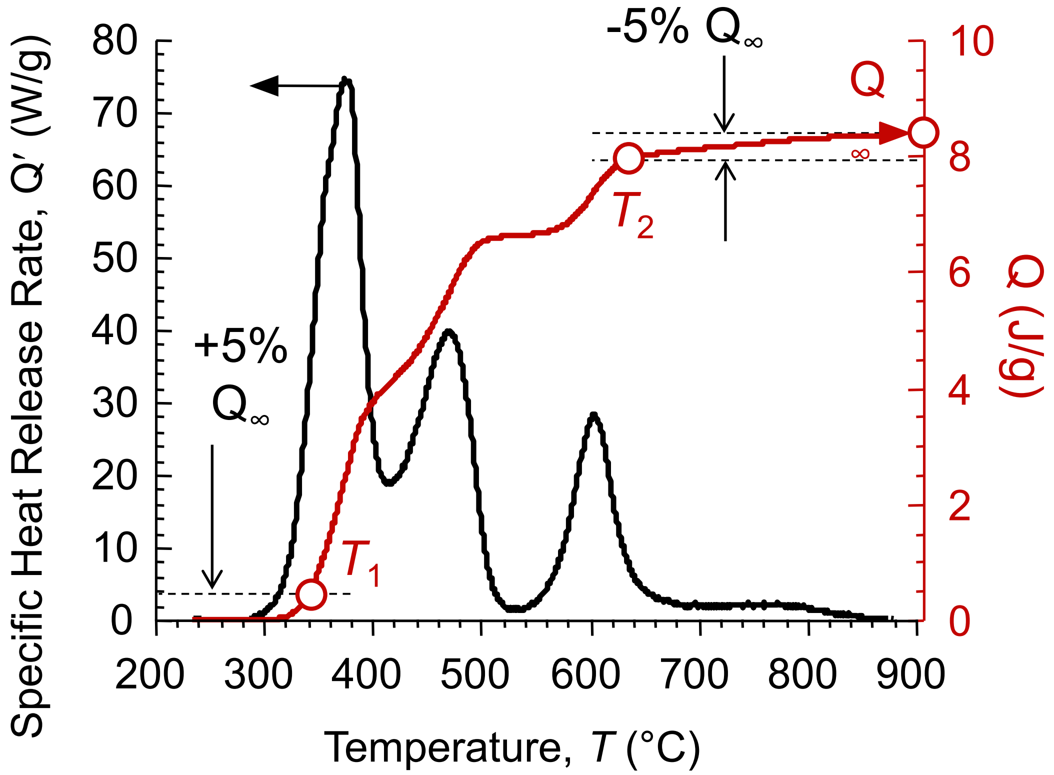
These MCC properties (heat release capacity, total heat release, ignition temperature, char yield have had **limited success as sole descriptors of pass/fail performance in bench scale fire tests.**

Molecular level fire growth parameter that combines all of these combustion properties was developed and tested.



Microscale Combustion Calorimeter (ASTM D7309-21)

- The *MCC* test measures materials properties related to flammability on a milligram size scale.
- One of the outputs: Fire Growth Capacity (*FGC*).
- The *FGC* is the ignitability and burning rate of the material, i.e., the **total fire hazard**



MCC procedure for FGC

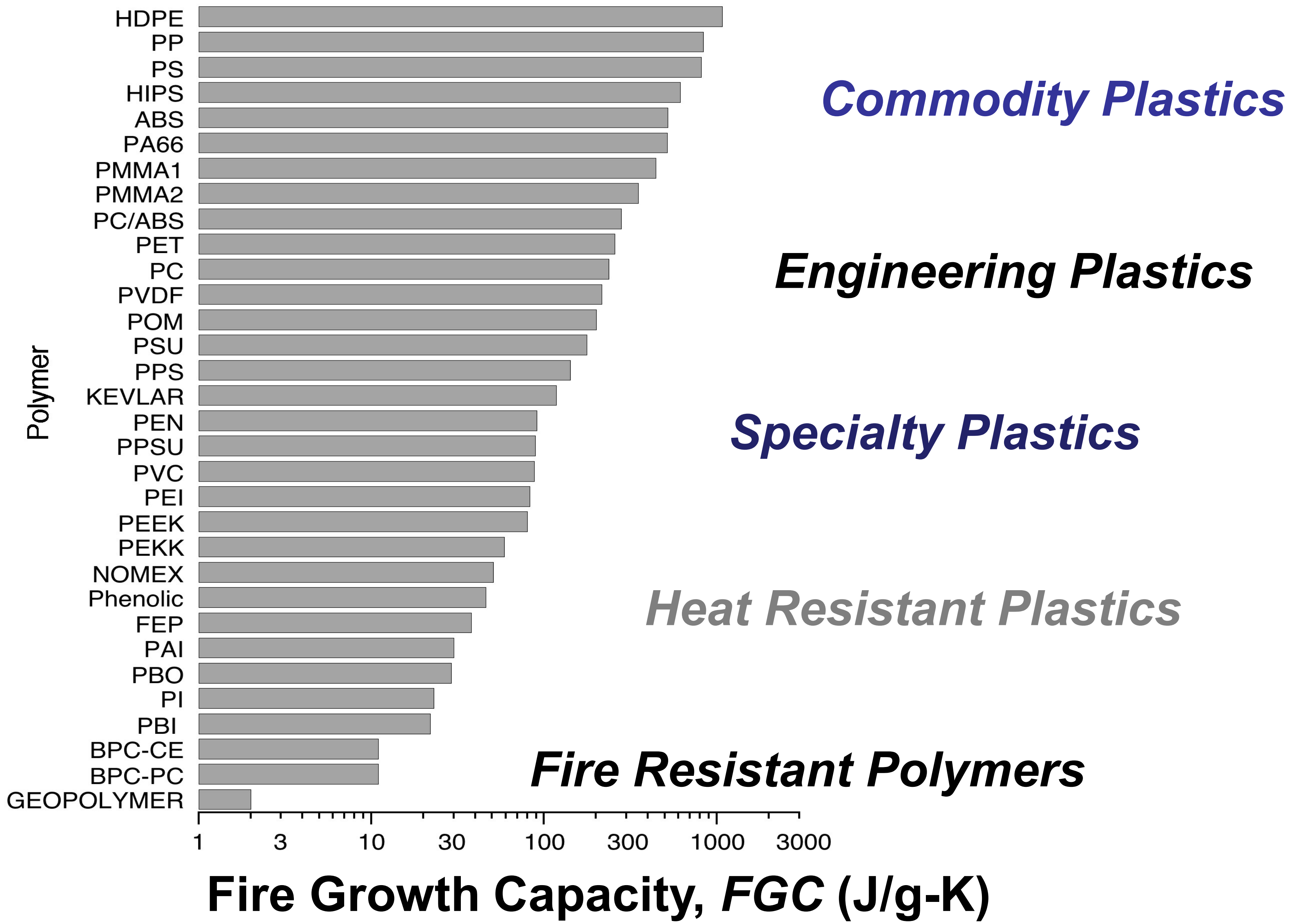
1. Measure specific heat release rate Q′ versus temperature *T* as per ASTM D7309 (5 replicates)
2. Integrate Q′/β versus *T* to obtain Q versus *T*, i.e., Q(*T*)
3. Obtain total heat release $Q(T_\infty) = Q_\infty = h_c$(J/g)
4. Obtain T_1 at 5% deflection from Q(T) baseline, i.e., at $0.05Q_\infty$
5. Obtain T_2 at Q_∞ i.e., $0.95Q_\infty$.
6. Calculate Fire Growth capacity (FGC)

T_0 = 25°C (298K)

T_1 = Ignition temperature

T_2 = Burning temperature

$$FGC = \left(\frac{Q_\infty}{T_2 - T_1}\right)\left(\frac{T_2 - T_0}{T_1 - T_0}\right)$$



HDPE
PP
PS
HIPS
ABS
PA66
PMMA1
PMMA2
PC/ABS
PET
PC
PVDF
POM
PSU
PPS
KEVLAR
PEN
PPSU
PVC
PEI
PEEK
PEKK
NOMEX
Phenolic
FEP
PAI
PBO
PI
PBI
BPC-CE
BPC-PC
GEOPOLYMER
Polymer
1
3
10
30
100
300
1000
3000
Fire Growth Capacity, *FGC* (J/g-K)
Commodity Plastics
Engineering Plastics
Specialty Plastics
Heat Resistant Plastics
Fire Resistant Polymers

Similarity project background

- Small changes in the composition of certified aircraft cabin materials are often needed due to unavailability of the original components or environmental regulations

- Recertification of the entire constructions are costly

- Aircraft manufactures and supplies petitioned the FAA to explore the alternative means of compliance in 2015

- Material Similarity Task Group was created to develop a method and criterion for comparing samples using ASTM D7309.

Similarity project goals

- **Develop** standardized guidance using the Microscale Combustion Calorimeter (MCC) to compare the flammability properties of combustible components of aircraft cabin materials.

- **Validate** Similarity Process through case studies comparing FAA fire test results to physically-based MCC flammability parameter.

- **Release** updated guidance documents.

14 CFR Bench Scale Fire Tests (Pass/Fail)

OSU Rate of Heat Release Apparatus
(Large Area Materials)
- Peak HRR
- 2-min HR

Radiant Panel
(Thermo-acoustic Insulation)
- Flame propagation distance
- After flame time

Vertical Bunsen Burner
(All other materials)
- Flame time
- Flame drip time
- Burn length

Validation case studies

Twelve industry case studies completed to validate MCC Similarity guidance:

- Phenolic resin systems
- Adhesives & potting compounds
- Decorative laminates
- Thermoplastics
- Paints/coatings
- Insulation blankets

Scope of variations: only constituents with **small** change due to FR additives, color, supplier, etc. were considered for substitutions.

Iterations of similarity approach

- ❑ MCC guidance document was presented on FAA website* on June 2016. Decision flow chart includes 2 MCC parameters HRC and HR.

- ❑ Revised MCC guidance document was presented in 2018. *FGC* was compared between samples using $t_{0.05}$ 95% confidence level

- ❑ Second revision of MCC document was presented as Task group report (2019). Approach included A/B and B basis criteria.

https://www.fire.tc.faa.gov/materials.asp

Recent Progress

1. FAA Tech Note on Physical Basis for Using FGC as a microscale flammability metric - *Completed* (DOT/FAA/TC-20/35)
2. FAA Tech Note on Similarity Criterion and Industry Case Studies – *Completed* (DOT/FAA/TC-20/30)
3. Journal article on Theoretical Basis for FGC published April 1, 2021 (*Polymer Degradation & Stability*)
4. 2021 version of ASTM D7309 to include FGC- *Completed*
5. FAA Tech Note on Microscale Flammability Criterion for Constituents of Aircraft Cabin Materials- *Completed*
6. *Draft Advisory circular (AC)* Microscale Combustion Calorimetry Test Method to Determine if a Material Change Requires Additional Certification testing for Flammability**

Similarity Determination

1. Five (5) samples of the original/certified constituent and five (5) samples the new/changed constituent are to be tested in accordance with ASTM D7309-21 (Method A) at heating rate β =1 K/s by a single operator using a single calibrated apparatus.

2. Calculate the five values of the FGC of the new/changed and the original/certified constituents.

$$FGC = \left(\frac{Q_\infty}{T_2 - T_1}\right)\left(\frac{T_2 - T_0}{T_1 - T_0}\right)$$

3. Calculate the arithmetic mean of the Fire Growth Capacity of the new/changed constituent (FGC_A) and the original/certified constituent (FGC_B).

Similarity Determination continued

4. Calculate the absolute value of the relative change in the mean Fire Growth Capacity of the new/substitute constituent compared to the original/certified constituent

$$\frac{\Delta FGC}{FGC_B} = \frac{|FGC_A - FGC_B|}{FGC_B}$$

5. The fire performance of materials and constructions containing a new/changed constituent will be equivalent (similar) to the original/certified constituent if the following criterion is met,

$$\frac{\Delta FGC}{FGC_B} \leq 0.30$$

Similarity Criterion

$$\frac{\Delta FGC}{FGC_B} \leq 2\frac{\sigma_B}{FAR_B} = 2\,COV_B = (2)(0.16) \approx 0.3$$

Average coefficient of variation, $COV_B = \frac{\sigma_B}{FAR_B}$ = 0.16 based on 69 FAR fire tests.

The 95% confidence level of certified FAR cabin materials is twice the standard deviation, σ_B.
The no-effect level of a change is equivalent to constraining the *relative change in FGC* to less than the uncertainty of the *FAR* fire test results.

The ***no-effect level of a constituent change is less than 30%*** at the 95% confidence level of FAR tests.

Summary

- FAA-industry working group has developed a process to compare flammability of materials at the molecular (milligram) level using MCC.

- A microscale combustion parameter representing ignitability and burning rate (*FGC*) is a discriminating predictor of standard fire test results for polymeric materials.

- It was demonstrated that the relative change in *FGC* of a substitute component should be similar to the expected variation of fire test results of cabin materials at the 95% confidence level.

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FAATC reports: https://www.fire.tc.faa.gov/Reports/reports.asp