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Material Change Similarity & Testing

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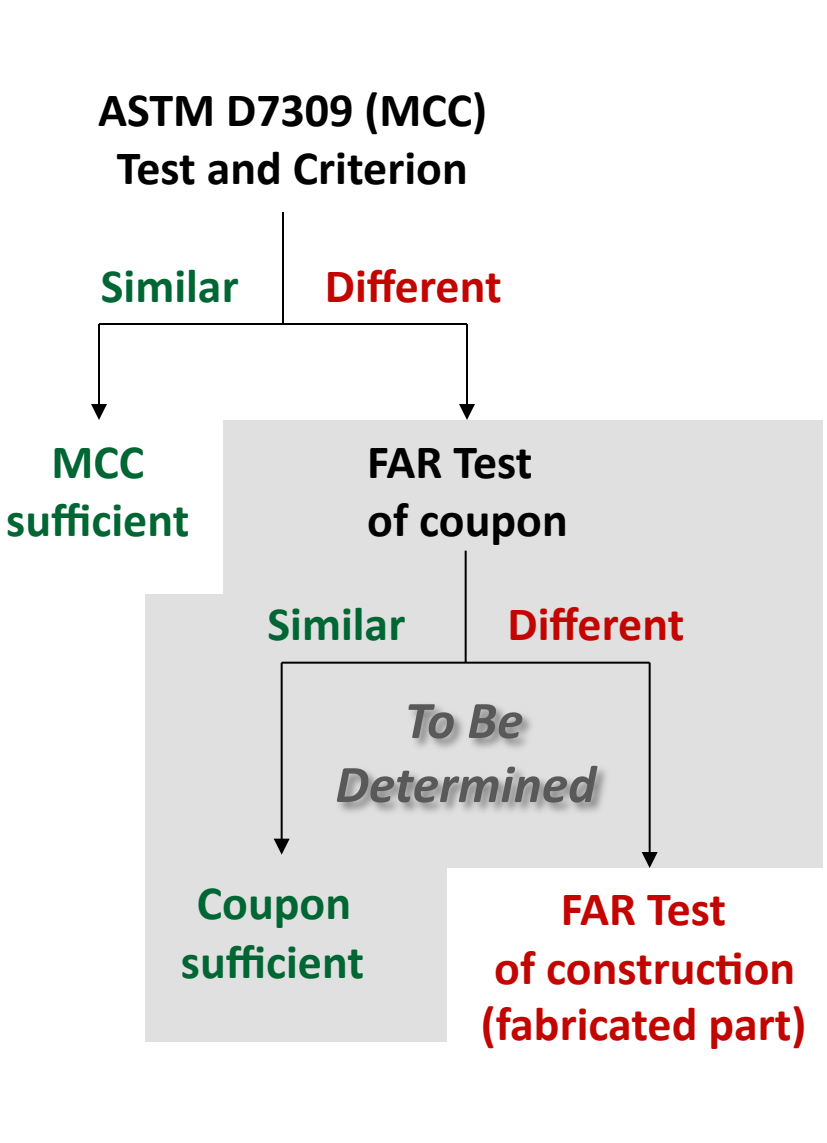
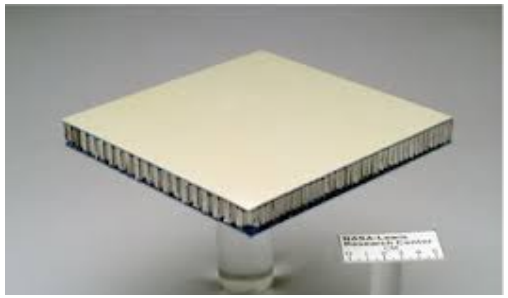
Proposed Method to Determine Similarity



Components
(mg)

Coupons (g)
(self supporting
components)

Constructions (kg)



Fire Size and MCC Properties

$$\text{Fire Size, } Q'(\text{W}) = Q'_0 \exp\left[\frac{t}{\tau}\right]$$

At early stages of fire when $t << \tau$,

$$Q'(t) = Q'_0\left(1+\frac{t}{\tau}\right) = Q'_0 + \frac{Q}{\tau} = Q'_0 + \beta\frac{Q}{(T_{ign} - T_0)}$$

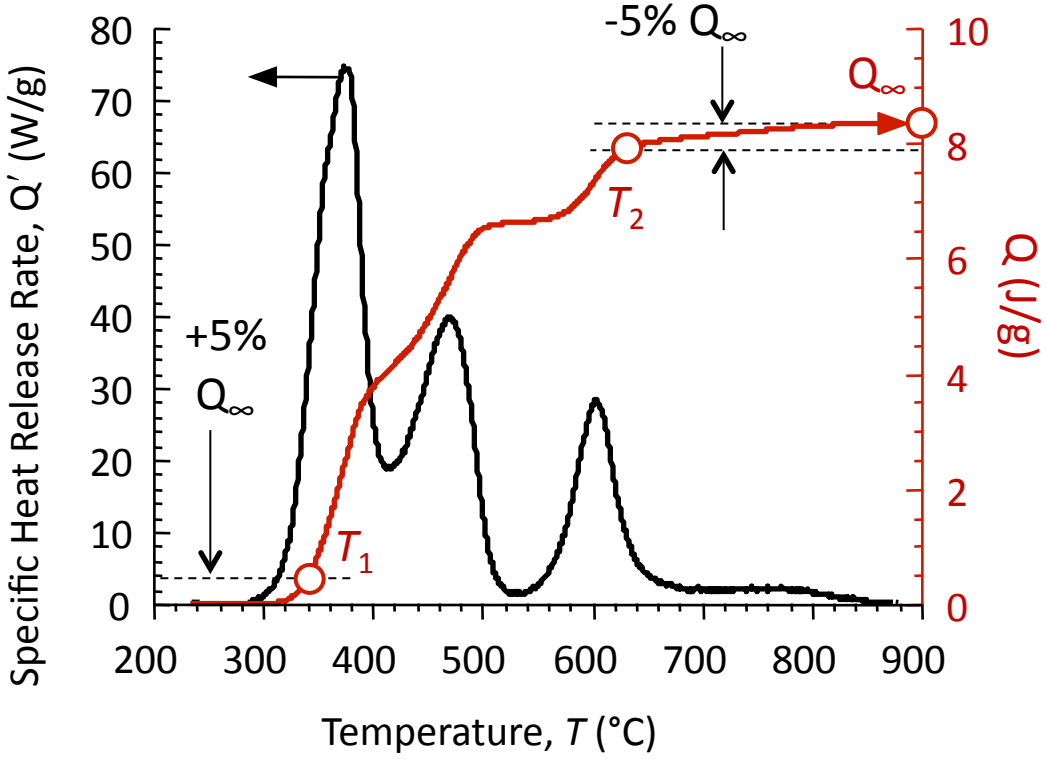
Normalizing for mass (m) and fire heat flux (β)

*Fire Growth Capacity (**FGC**)*

$$= \frac{Q'}{m\beta} = \frac{Q'_0/m}{\beta} + \frac{Q/m}{(T_{ign} - T_0)}$$

Heat Release Capacity (HRC) + *Ignition Capacity (IGC)*

Parametric Representation of Flammability Fingerprint for Comparison Purposes



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 $Q(T_\infty) = Q_\infty$(J/g)

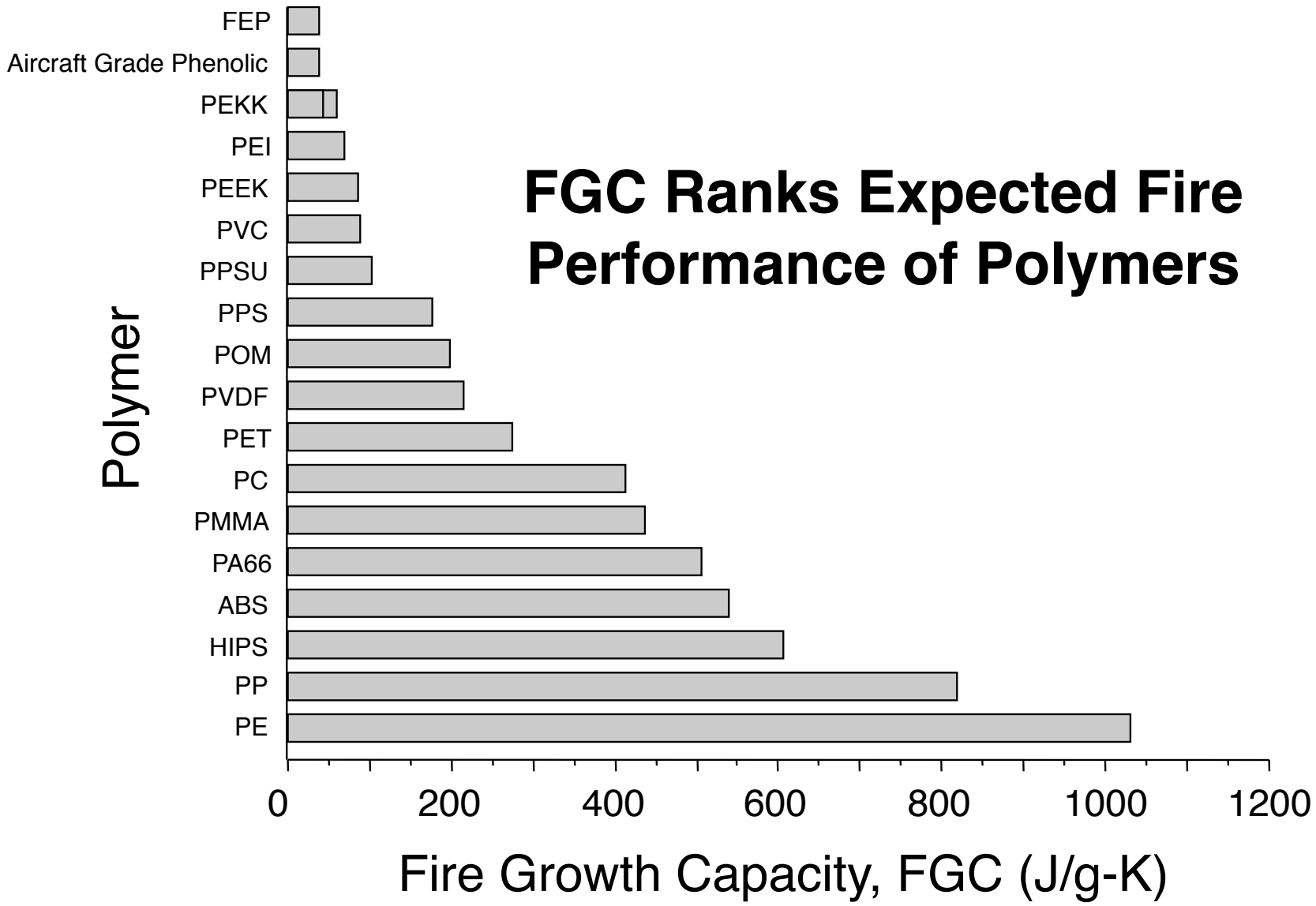
4. Obtain T_1 at 5% deflection from Q(T) baseline, i.e., at $0.05Q_\infty$

5. Obtain T_2 at $0.95Q_\infty$.

6. Calculate Fire Growth Capacity, FGC = HRC + IGC,

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

T_0 = Room Temperature = 25°C
T_1 = Ignition temperature
T_2 = Burnout temperature


FGC Ranks Expected Fire Performance of Polymers
Polymer
FEP
Aircraft Grade Phenolic
PEKK
PEI
PEEK
PVC
PPSU
PPS
POM
PVDF
PET
PC
PMMA
PA66
ABS
HIPS
PP
PE
0
200
400
600
800
1000
1200
Fire Growth Capacity, FGC (J/g-K)

Similarity Criterion (*t*-Test)

$$t = \frac{\left|FGC_1 - FGC_2\right|}{s_p\sqrt{\frac{1}{n_1} + \frac{1}{n_2}}} \le t_{0.05}(\nu)$$

If, $t \le t_{0.05}(\nu)$, there is a 95% chance that $FGC_1 = FGC_2$.

t = Test statistic

n_i = Number of replicate MCC tests

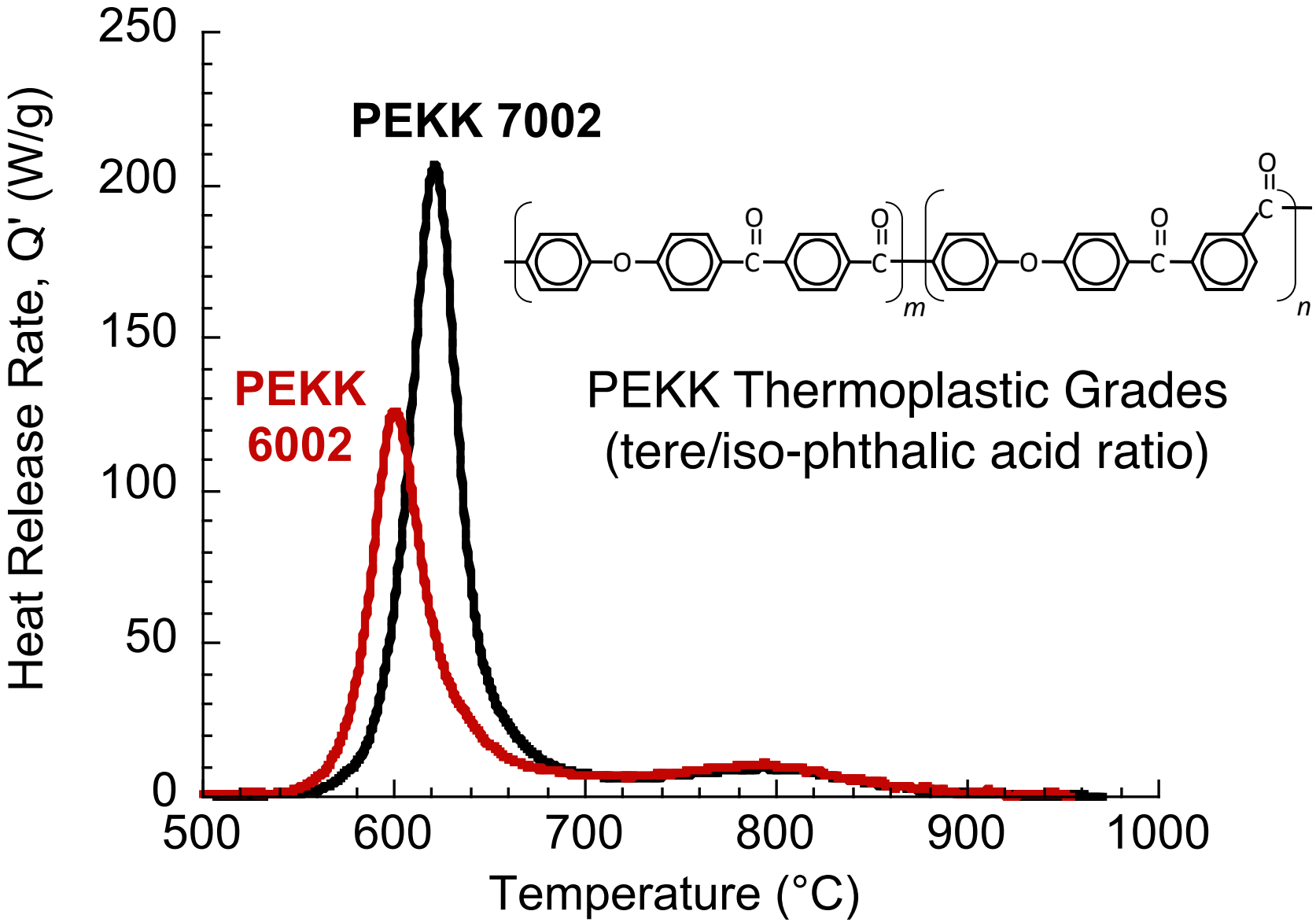
$t_{0.05}(\nu)$ = Value of Student's t distribution for small sample size with $\nu = n_1 + n_2 - 2$ degrees of freedom

$n_1 = n_2 =$	5	6	7	8	9	10
$t_{0.05}(\nu) =$	2.306	2.228	2.179	2.145	2.120	2.101

s_1, s_2 = Standard deviations of FGC_1, FGC_2

s_p = Pooled standard deviation = $\sqrt{\frac{(n_1 - 1)s_1^2 + (n_2 - 1)s_2^2}{n_1 + n_2 - 2}}$

Flammability Fingerprints of PEKK



Comparison of PEKK Grades (6002 vs 7002)

PEKK Grade	Morphology	FGC (J/g-K)
6002	Amorphous	43 ± 2
7002	Semi-crystalline	59 ± 2

$t = 9.35$

$t_{0.05}(4) = 2.365$

$t \geq t_{0.05}(4)$ ➔ ***Different***

Comparison of PEKK 7002 Thermal History

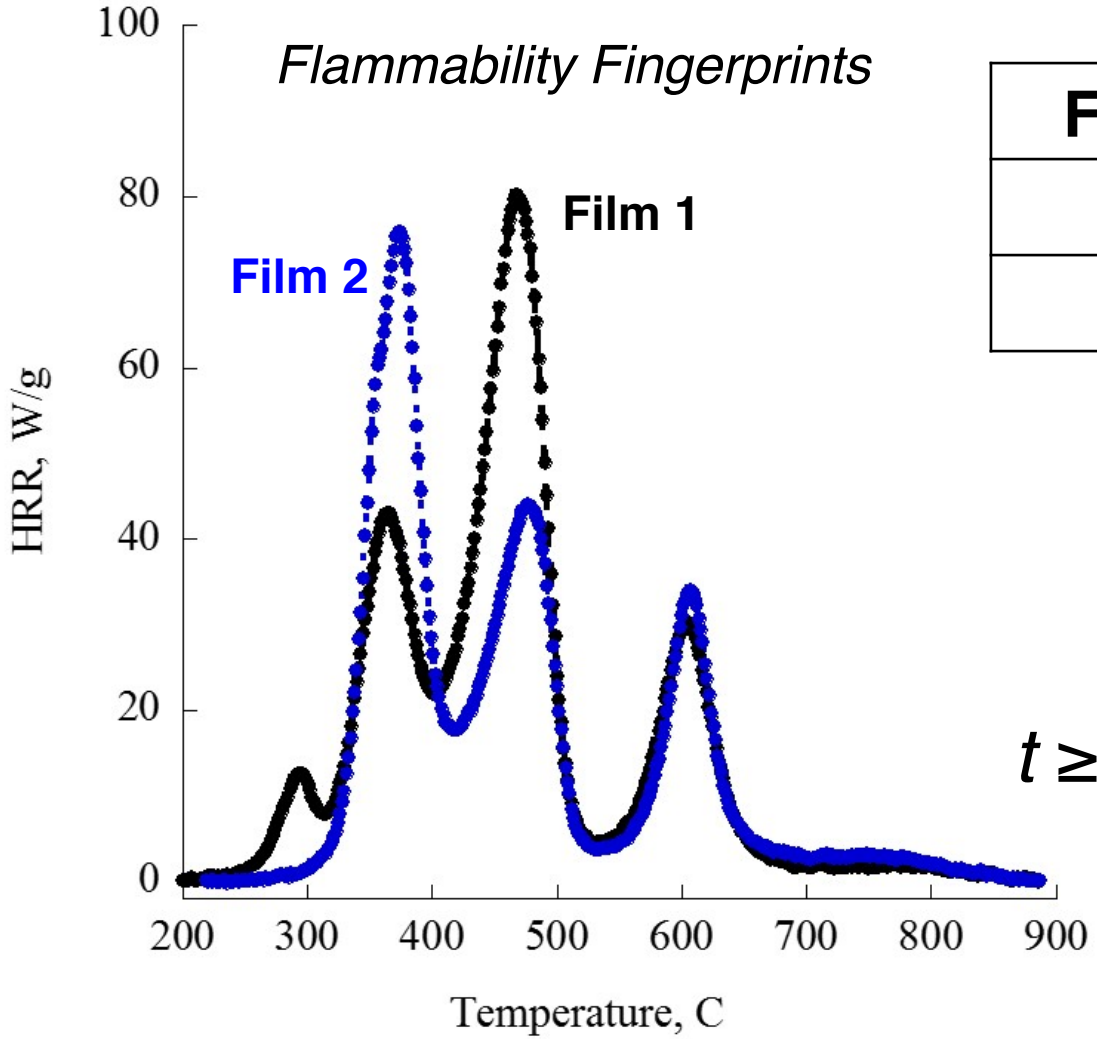
PEKK 7002 Thermal History	FGC (J/g-K)
Quenched (amorphous)	59 ± 2
Annealed (Semi-crystalline)	57 ± 2

$t = 1.22$

$t_{0.05}(4) = 2.776$

$t \leq t_{0.05}(4)$ ➔ ***Similar***

Comparison of Thermoplastic Films

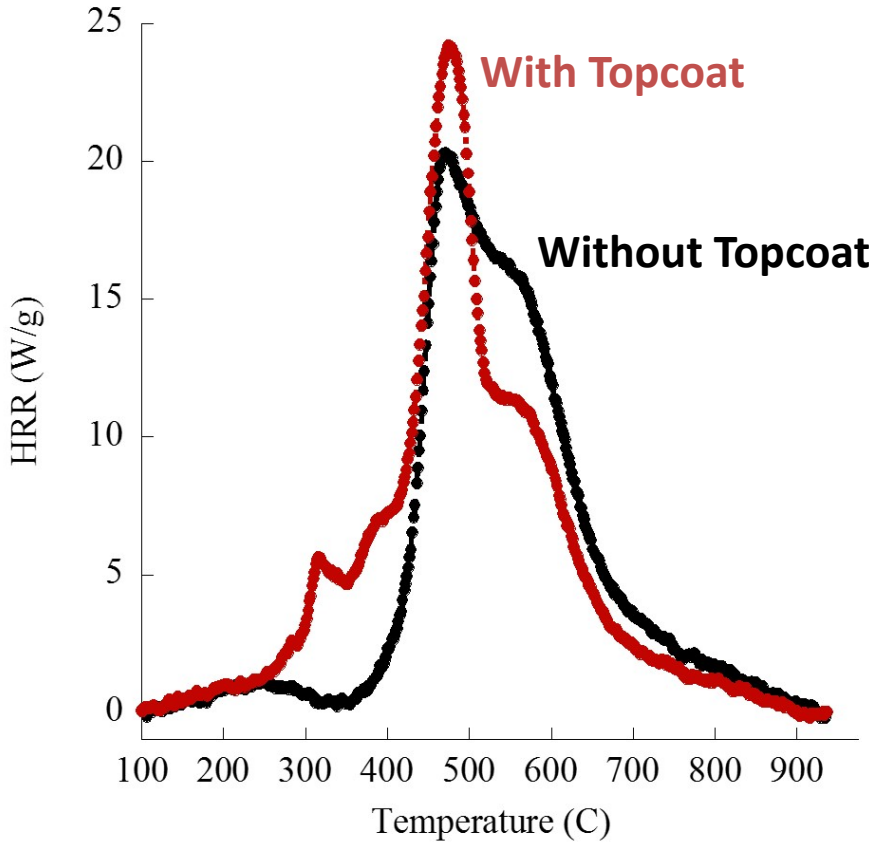


Film	FGC (J/g-K)
1	69 ± 3
2	57 ± 3

$$t = 4.9$$

$$t_{0.05}(4) = 2.776$$

$$t \geq t_{0.05}(4) \rightarrow \textit{Different}$$



Effect of Topcoat on MCC of Phenolic / Fiberglass Lamina

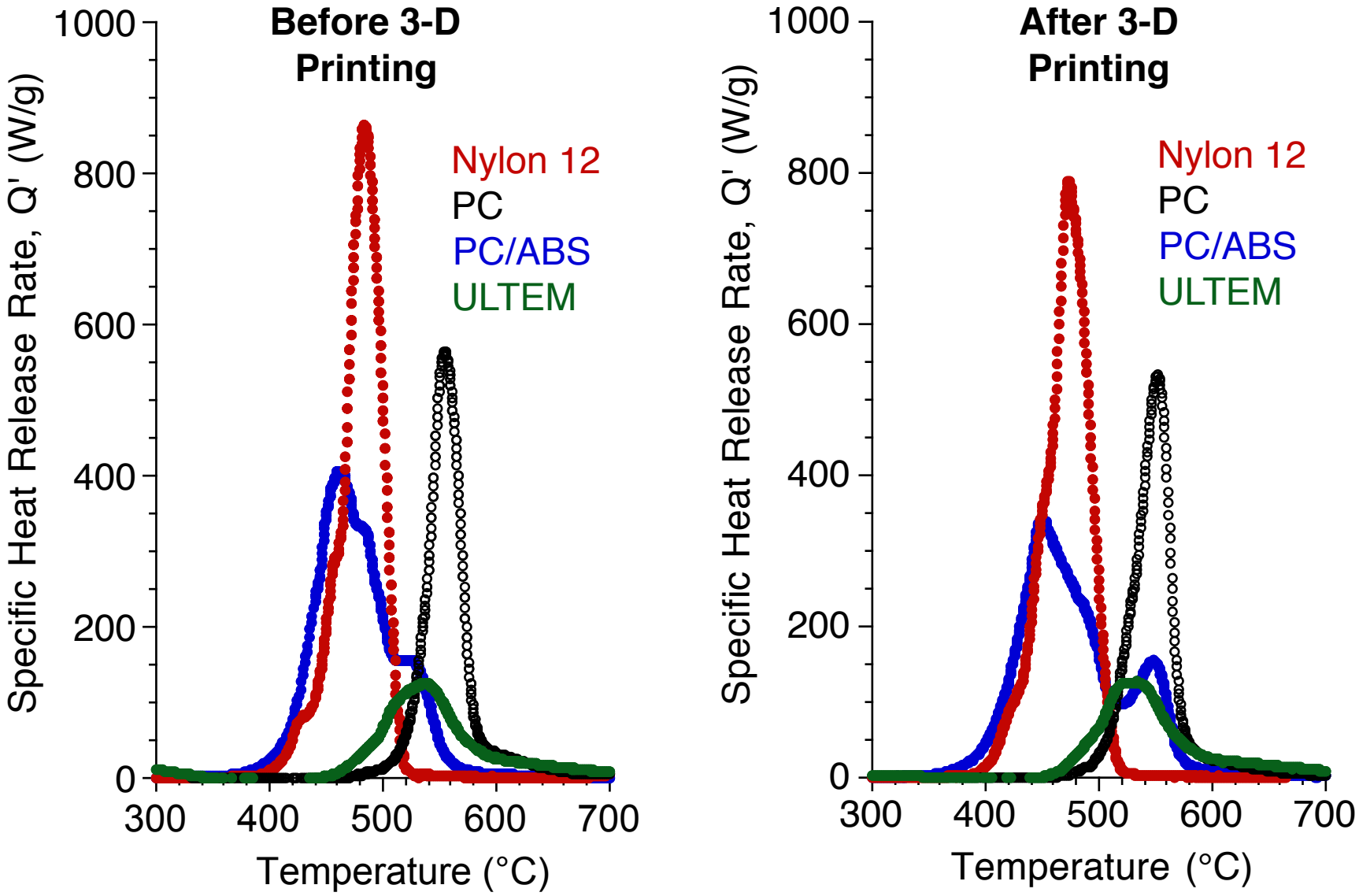
$t = 1.44$

$t_{0.05}(4) = 2.776$

$t \leq t_{0.05}(4)$ ➔ ***Similar***

Phenolic / Glass Lamina	FGC (J/g-K)
With topcoat	26 ± 2
Without top coat	23 ± 3

Effect of 3-D Printing on Flammability Fingerprint

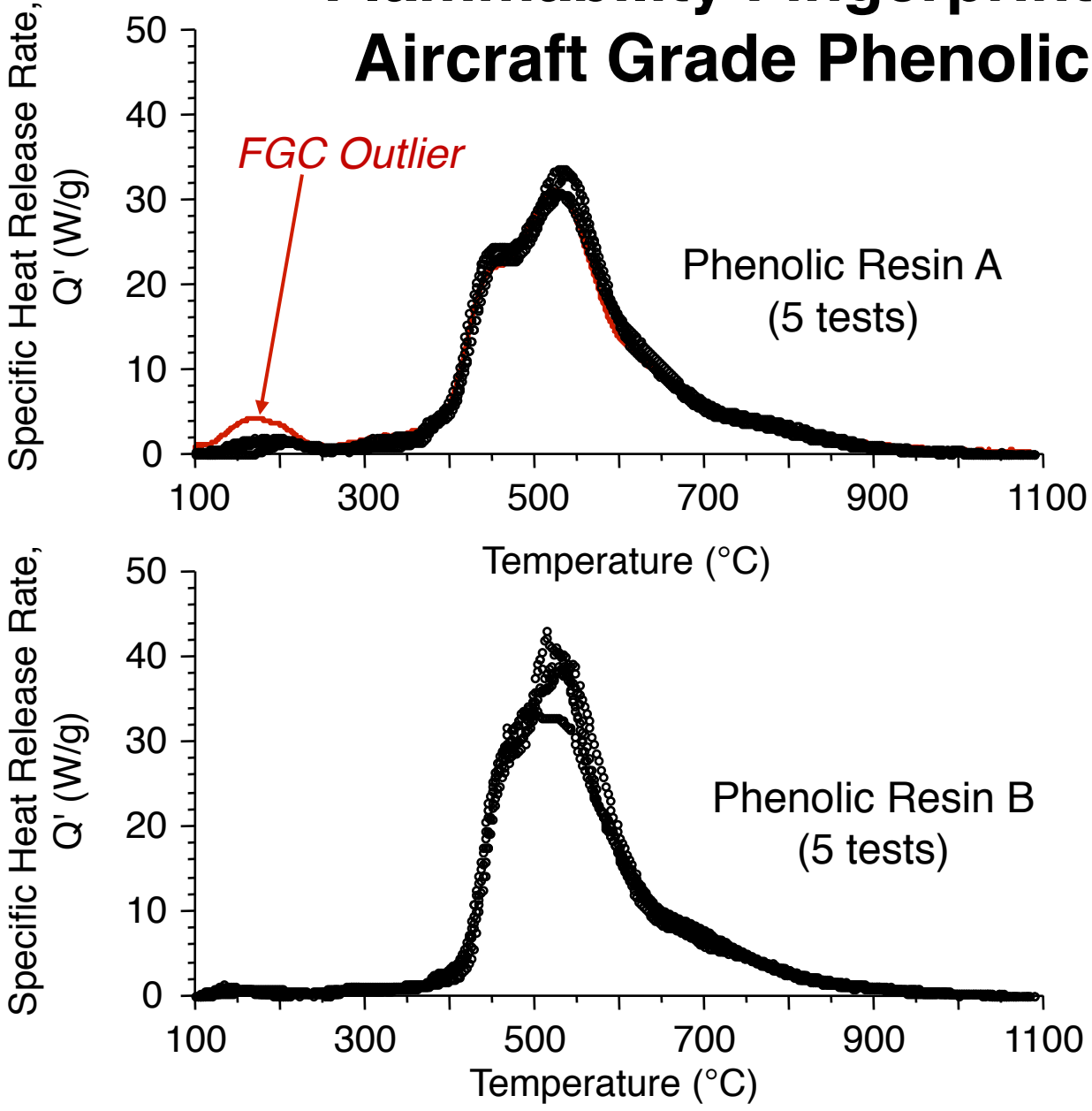


Effect of 3-D Printing on Fire Growth Capacity of Polymers

3-D Printing Polymer	***Before Printing*** FGC (J/g-K)	***After Printing*** FGC (J/g-K)	MCC Criterion ($n_1 = n_2 = 5$)
Nylon-12	599 ±11	575 ± 11	***Different***
PC/ABS	330 ± 24	290 ± 5	***Different***
PC	250 ± 6	248 ± 11	***Similar***
ULTEM	73 ± 3	73 ± 3	***Similar***

Heat resistant plastics

Flammability Fingerprints of Two Aircraft Grade Phenolic Resins

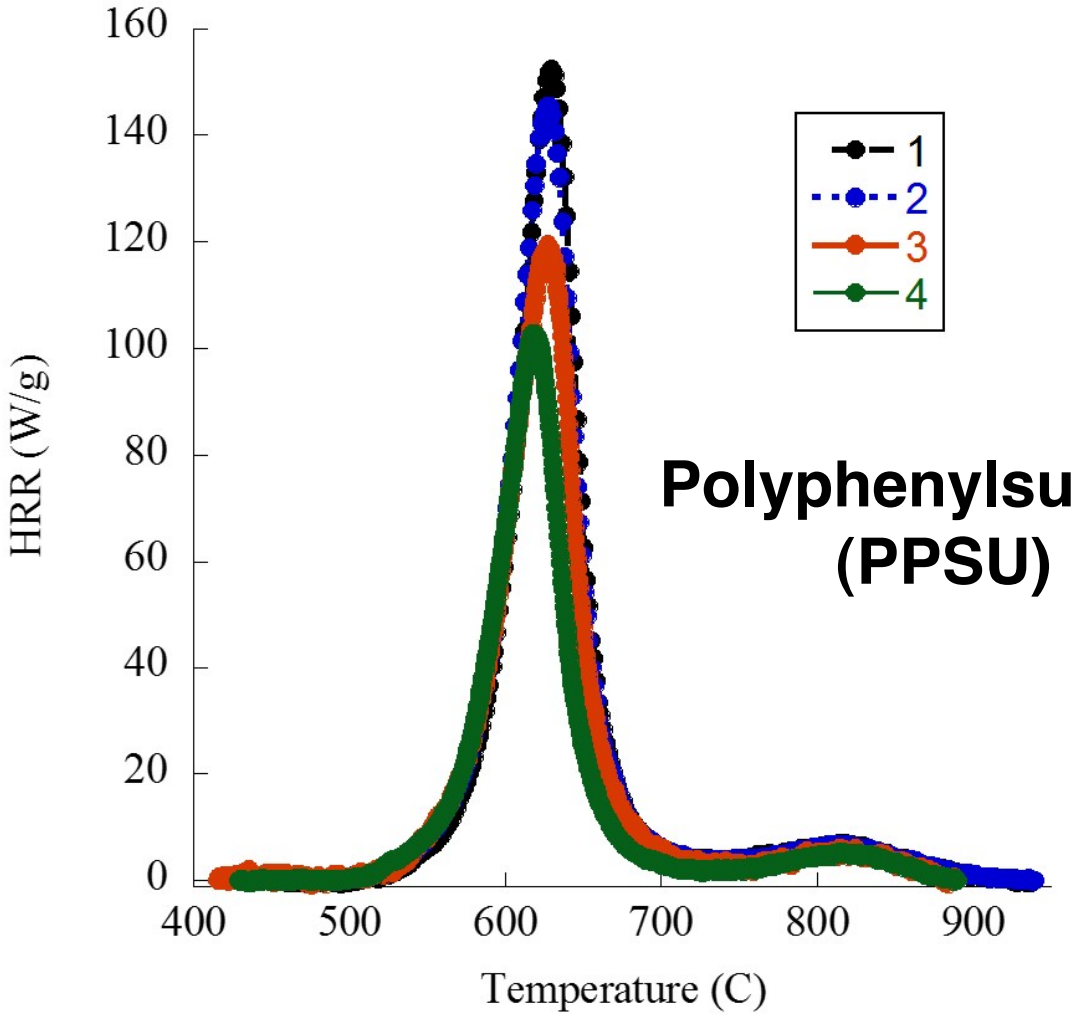


Comparison of Two Aircraft Grade Phenolic Resins

Phenolic Resin A FGC, J/g-K (*number of tests*)	**Phenolic Resin B** FGC, J/g-K (*number of tests*)	**MCC Criterion**
38 ± 3 (5)	38 ± 1 (5)	***Similar* (*n* = 5)**
36 ± 1 (4*)	38 ± 1 (5)	***Different* (*n* = 4)**

* Minus 1 legitimate outlier

Pair-Wise Comparison of Material and Process Variations



Sample	FGC (J/g-K)	MCC result
1	59 ± 2	
2	57 ± 1	Similar
1	59 ± 2	
3	50 ± 1	Different
1	59 ± 2	
4	44 ± 4	Different
2	57 ± 1	
3	50 ± 1	Different
2	57 ± 1	
4	44 ± 4	Different
3	50 ± 1	
4	44 ± 4	Different

Conclusions

Proposed MCC Method and Similarity Criterion is:

- Sensitive to changes in composition at 10 mg scale
- Sensitive to outliers ($n \geq 5$ recommended).
- More sensitive to changes in composition than FAR tests.*

*IAMFTWG Meetings, April & June, 2018