FLAMMABILITY OF POLYMER COMPOSITES

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Federal Aviation Administration

Atlantic City, NJ October 31, 2007

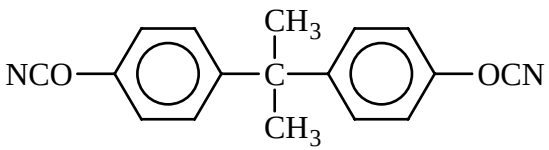
Samples

Bisphenol-A (BPA) Cyanate Ester & Epoxy

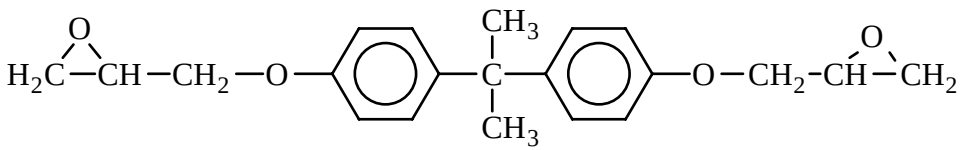
Bisphenol-C (BPC) Cyanate Ester & Epoxy

Silicone Resin (Dow Corning)

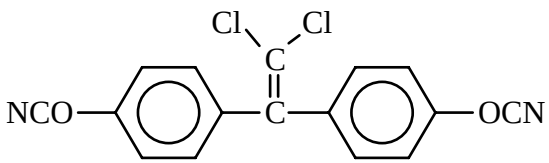
Aerospace Epoxy Composite (Already Fabricated as Composite)



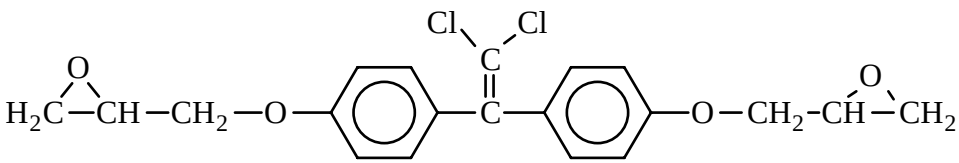
BPACE



BPAE



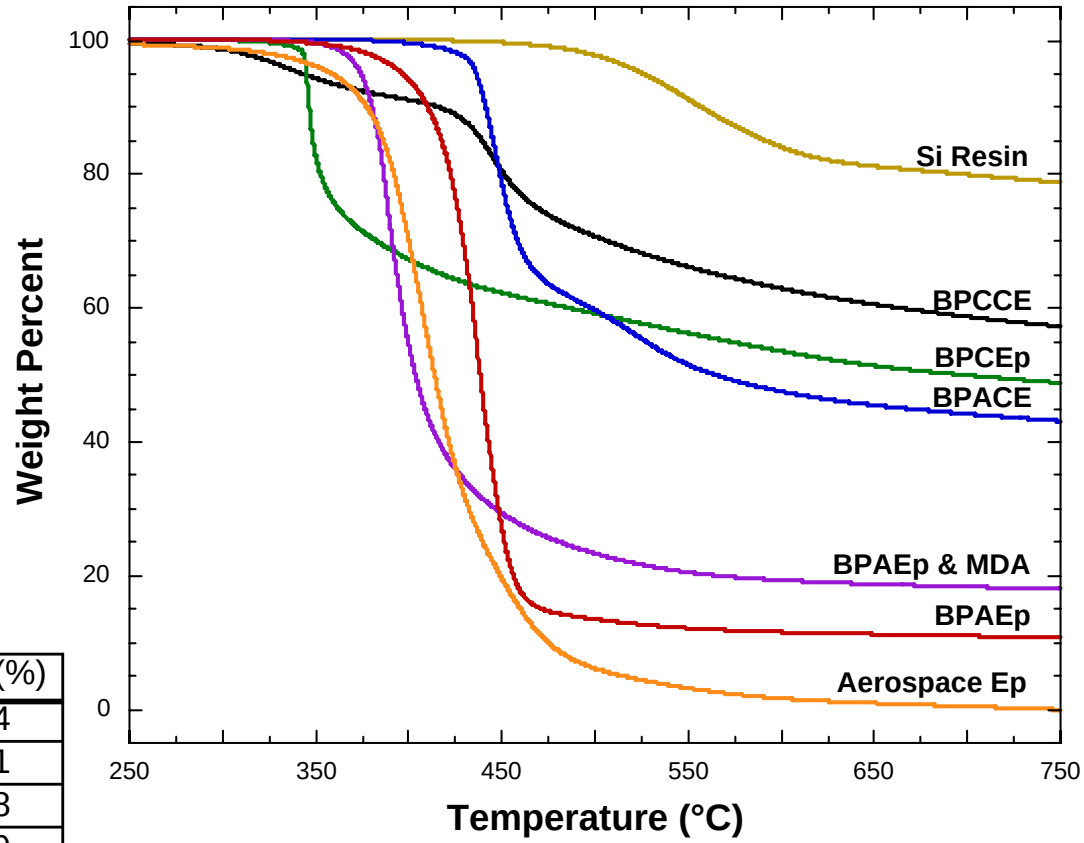
BPCCE



BPCE

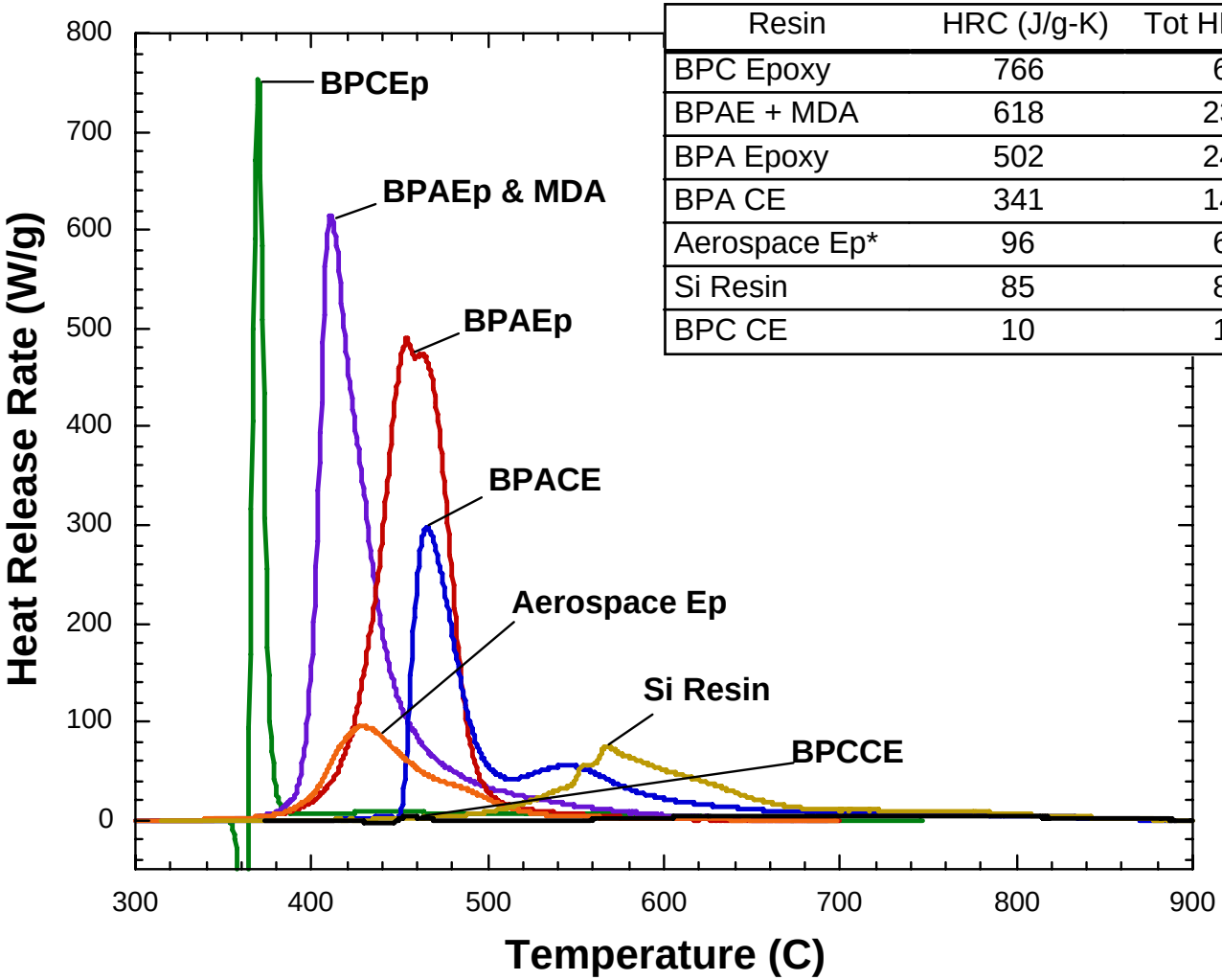
Thermogravimetric Analysis

Resin	Onset (°C)	Tp (°C)	Char (%)
Si Resin	490	543	77.4
BPC CE	422	437	55.1
BPC Epoxy	342	345	46.8
BPA CE	428	440	41.9
BPAE + MDA	373	384	16.2
BPA Epoxy	411	432	9.5
Aerospace Ep*	374	403	73.3



- TGA of resin only
- 10°C/min in Nitrogen
- Char @ 900°C

Microscale Combustion Calorimeter

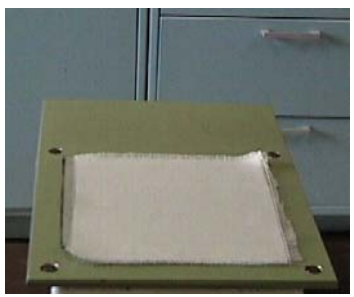
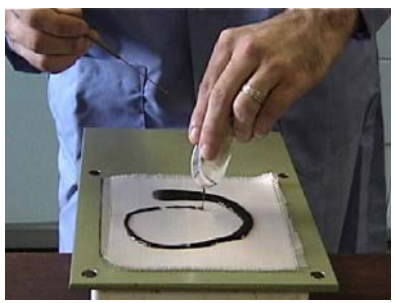
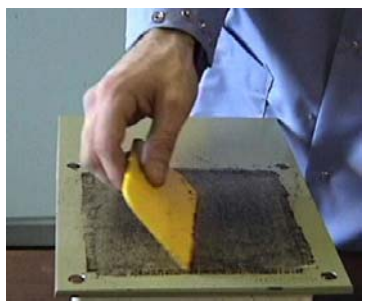


Resin	HRC (J/g-K)	Tot HR (kJ/g)	Tp (C)	Char (%)
BPC Epoxy	766	6.2	371	39.9
BPAE + MDA	618	23.8	411	12.7
BPA Epoxy	502	24.8	455	7.1
BPA CE	341	14.8	468	42.4
Aerospace Ep*	96	6.8	430	72.2
Si Resin	85	8.9	572	77.5
BPC CE	10	1.2	681	61.5

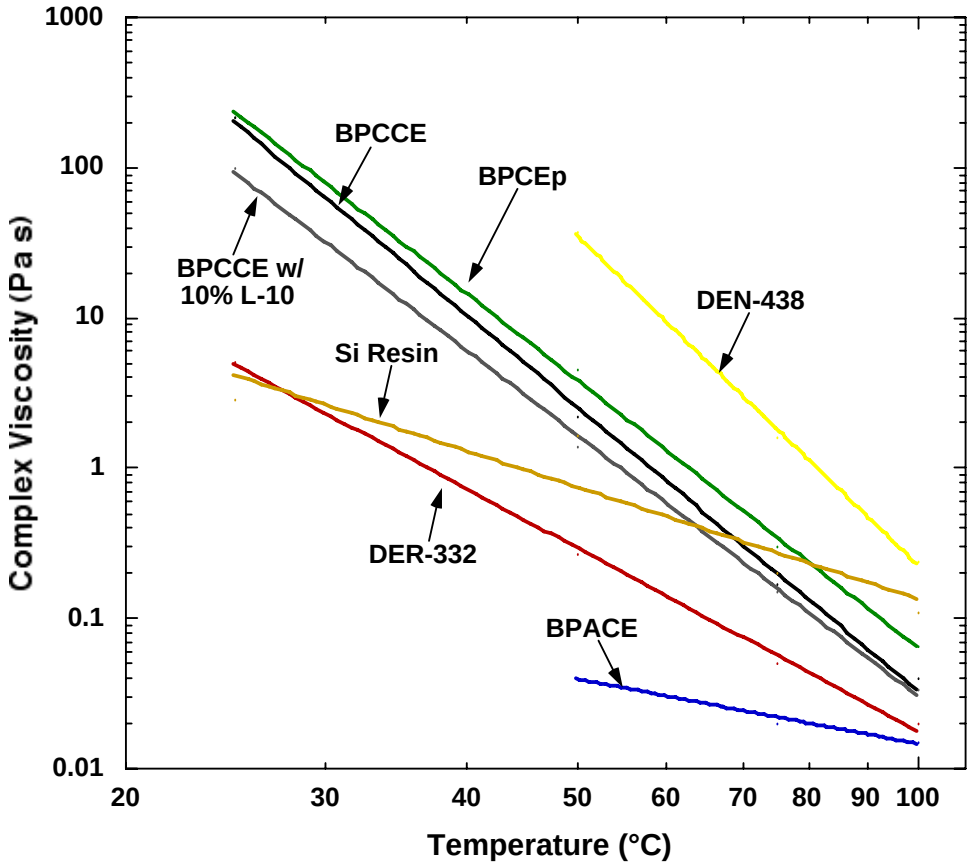
ASTM D7309-07

Hand Lay-Up of Composites

- Single ply laminates were made using hand lay-up
- Samples were pressed between two Teflon coated aluminum plates with shims and placed into a heated press for curing
- Samples were trimmed to final dimensions for fire testing
- Resulting panels had ~40% resin content
- Simulates end use as aircraft laminate

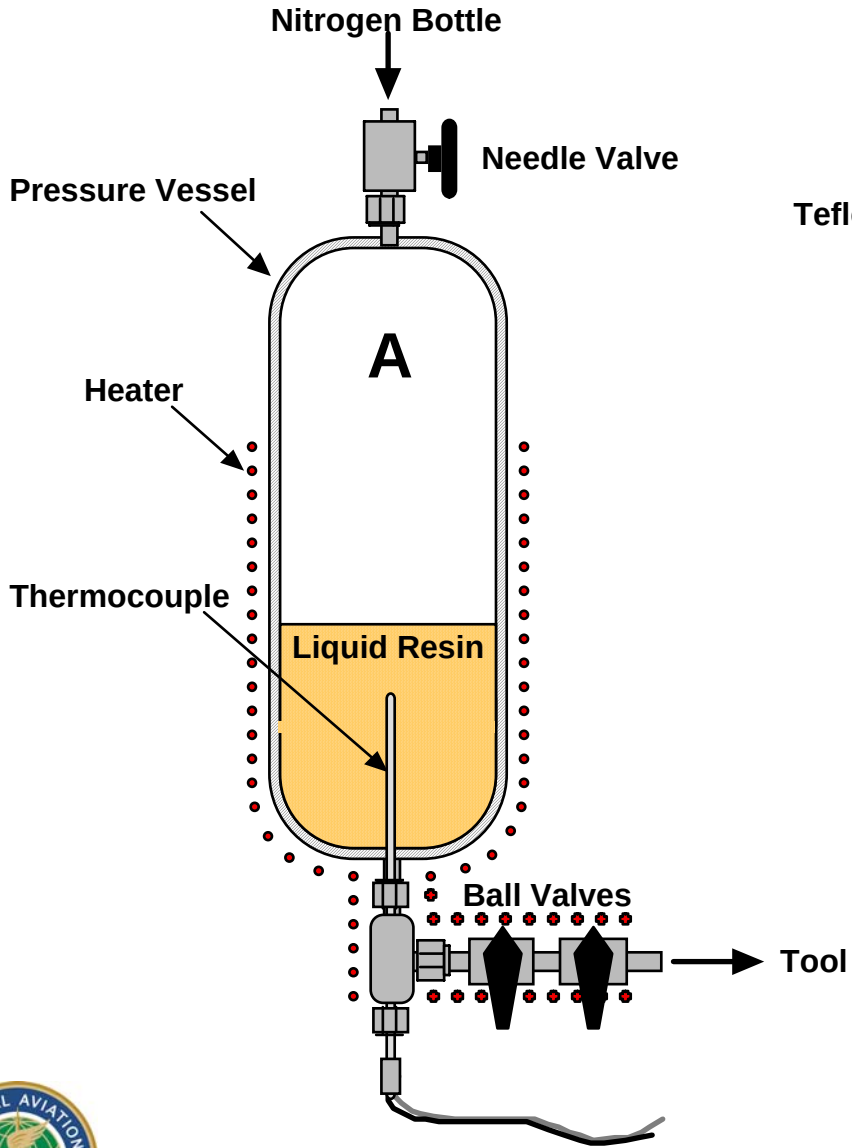




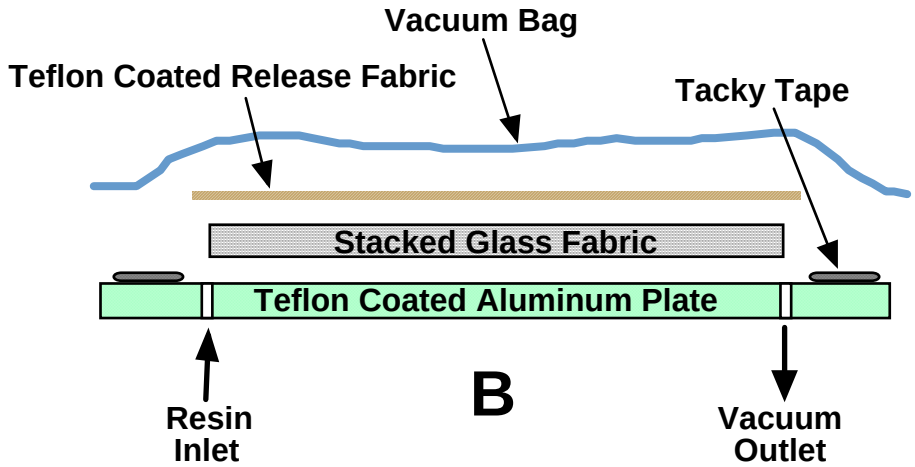
Liquid Resin Viscosities



- 50 mm parallel plates with ~ 0.5 mm gap
- 10% strain at 1Hz from 25 to 100°C
- Helped to determine processing temperatures

VARTM Apparatus





- 18 Plies of glass fabric
- Entire system is heated
- Pressure applied to vessel
- Vacuum applied to tool

Structural Composites

Video Deleted

Fabrication of Samples

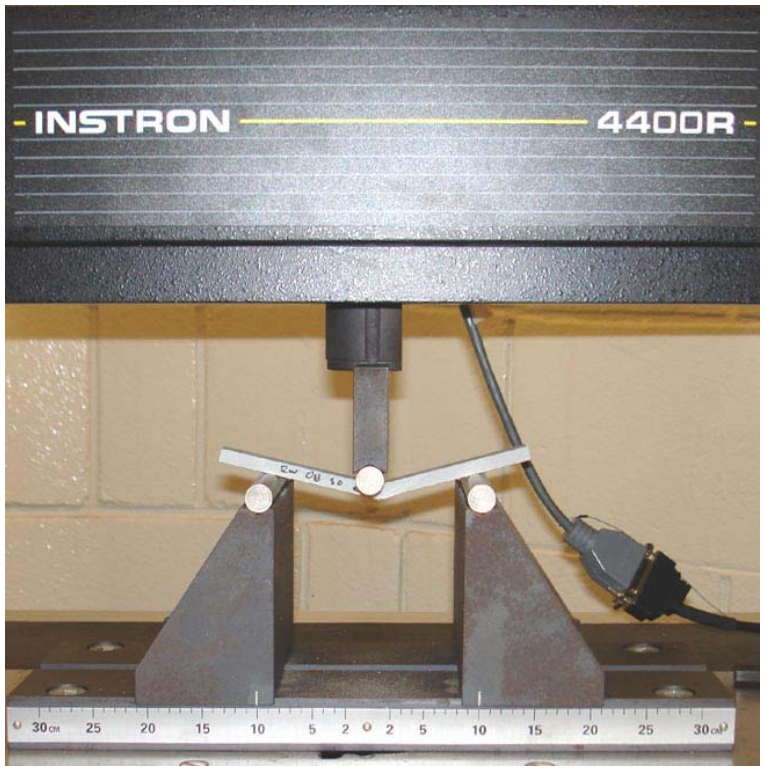
Small VARTM Samples - 6” x 10”

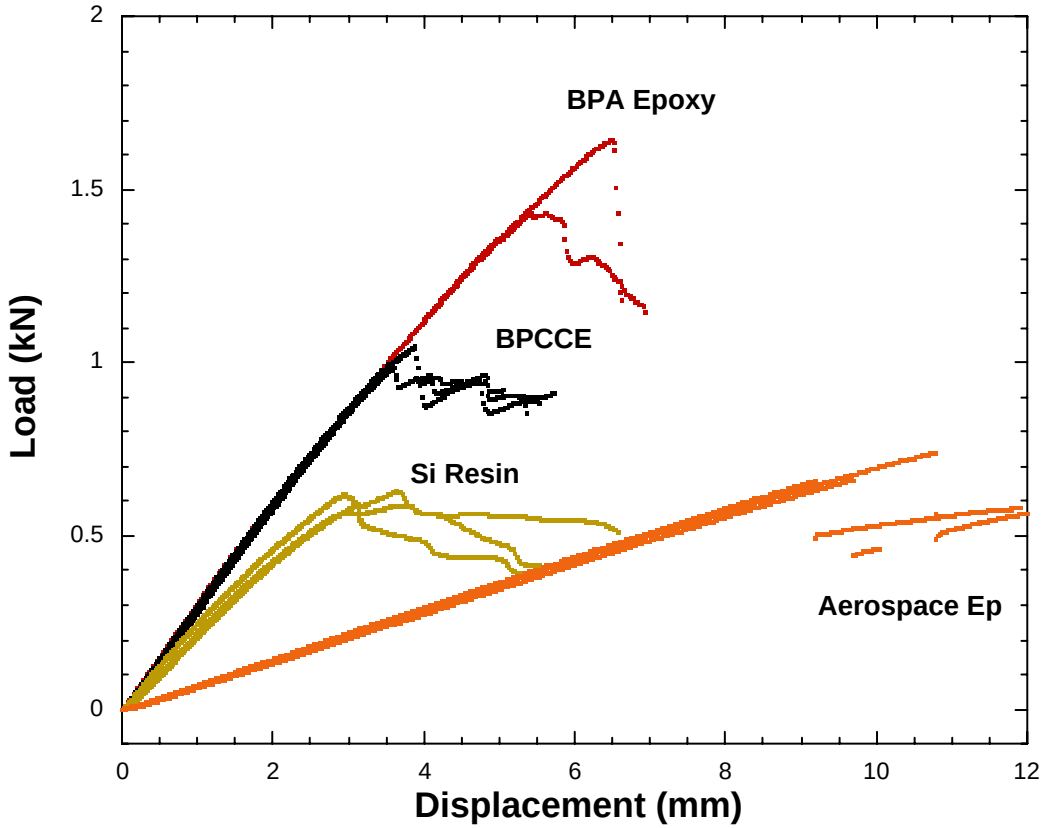
Large VARTM Samples - 14” x 14”

BPA Epoxy

BPC CE

Mechanical Tests - ASTM D790





Sample Dimensions: **150mm x 12.5mm x 6.4mm**

Aerospace Epoxy (3mm)

Span Length: **100mm**

Crosshead Speed: **2.8mm/min**

Mechanical Properties - 3 Point Flex Test

16-Ply Quasi-Isotropic Carbon Fiber

18-Ply 8HS Weave Glass Fiber

Resin	Yield Stress (MPa)	Yield Strain (%)	Flexural Modulus (GPa)
Aerospace Ep*	800	1.8	47
BPA Epoxy	620	2.3	29
BPA CE	570	1.8	32
BPC CE	520	2.2	26
BPAE + MDA	500	1.6	32
BPC Epoxy**	490	2.1	25
Si Resin	220	1.1	24

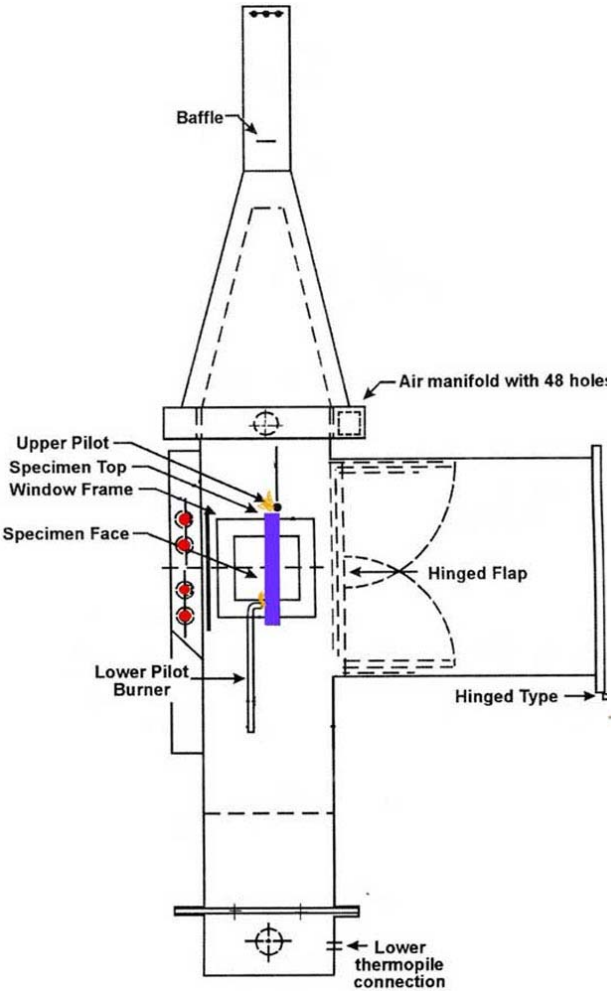
*Sample was tested as received in 3-mm thickness

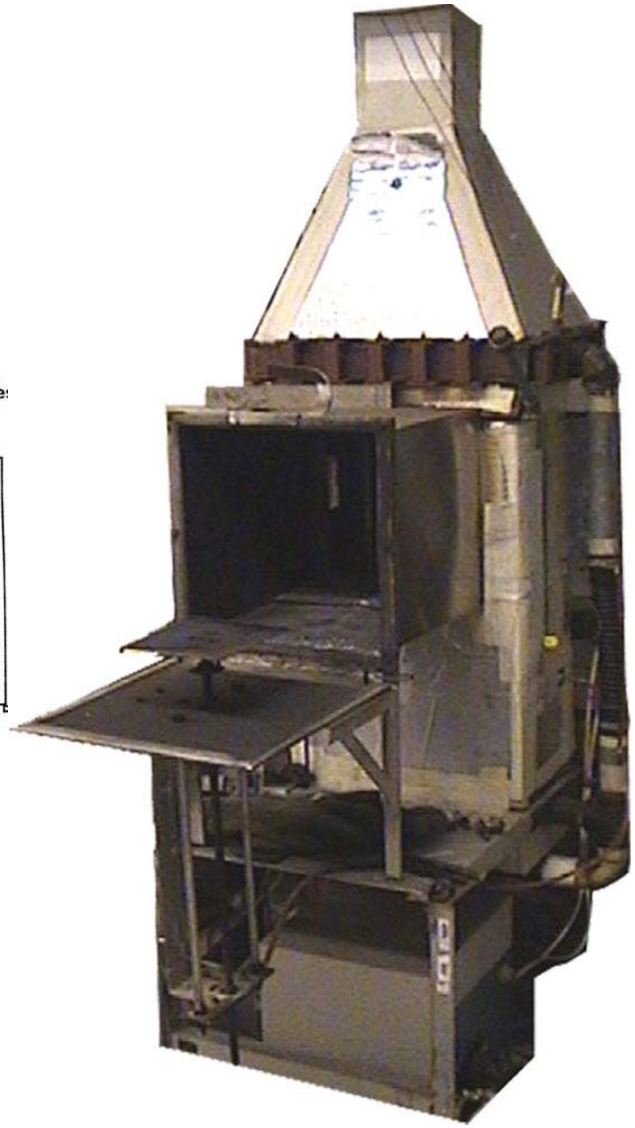
**Result from a single test due to a limited amount of sample

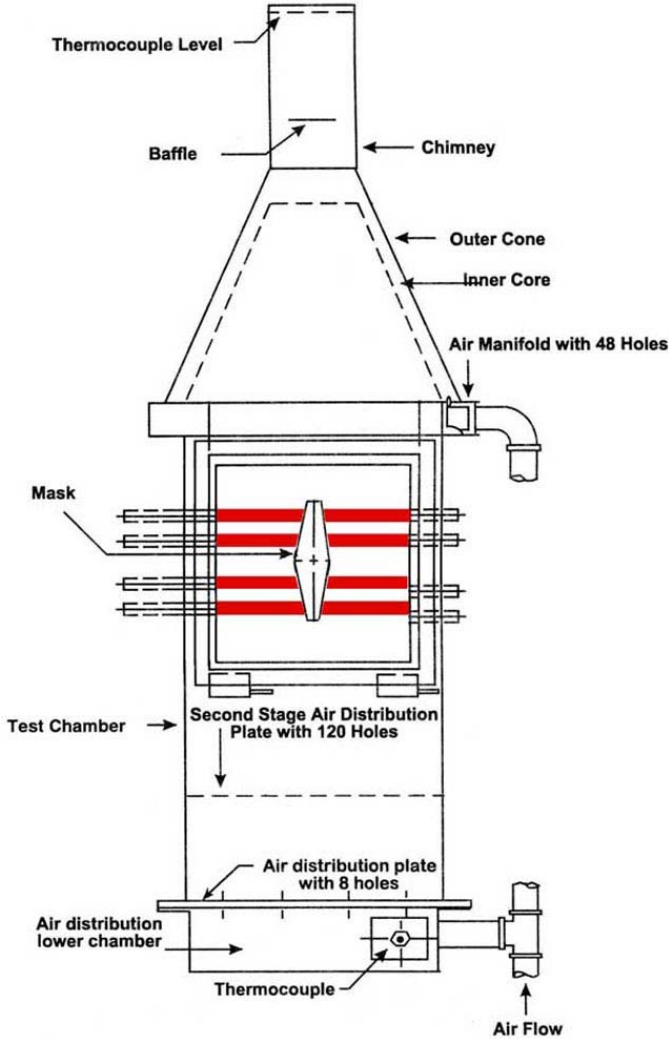
- Resin-rich BPC Epoxy failed by shear

- All other samples failed by tension/compression

OSU Calorimeter

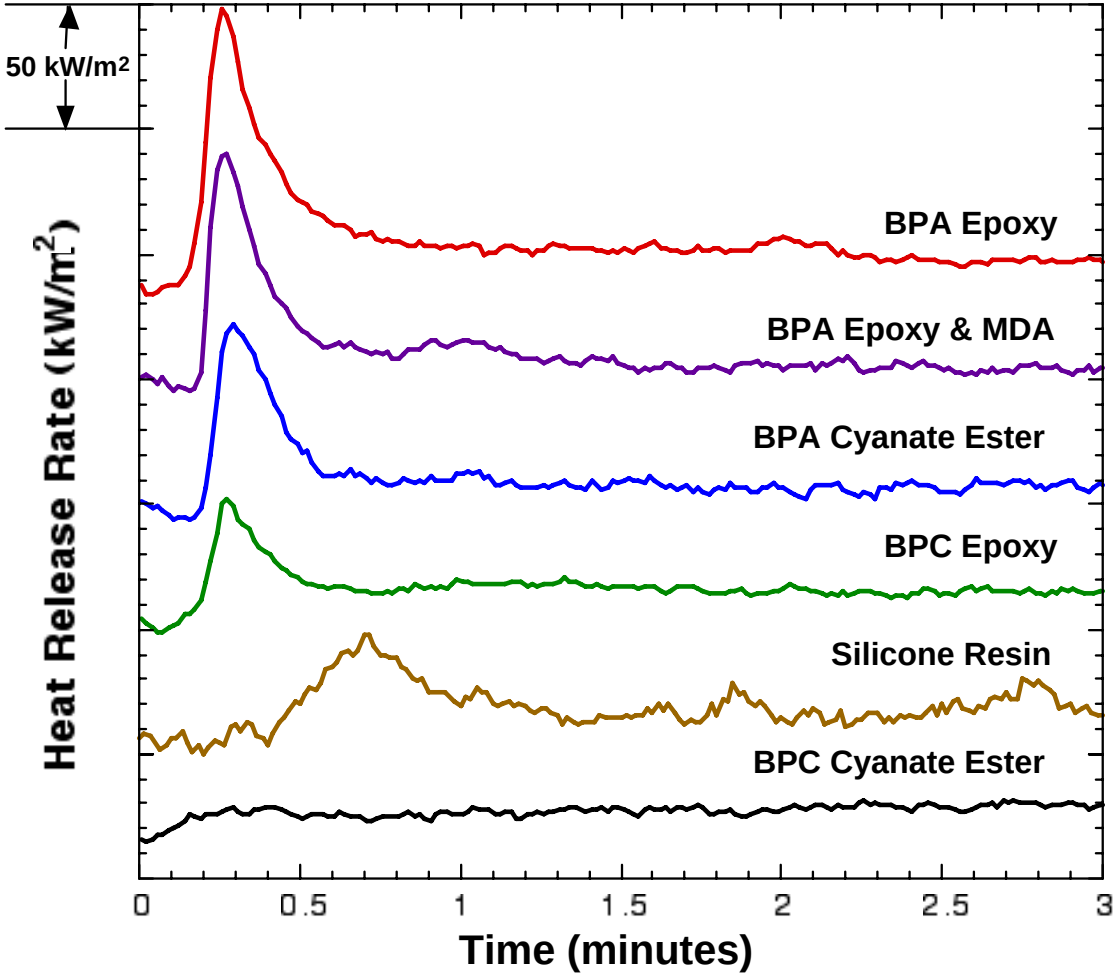




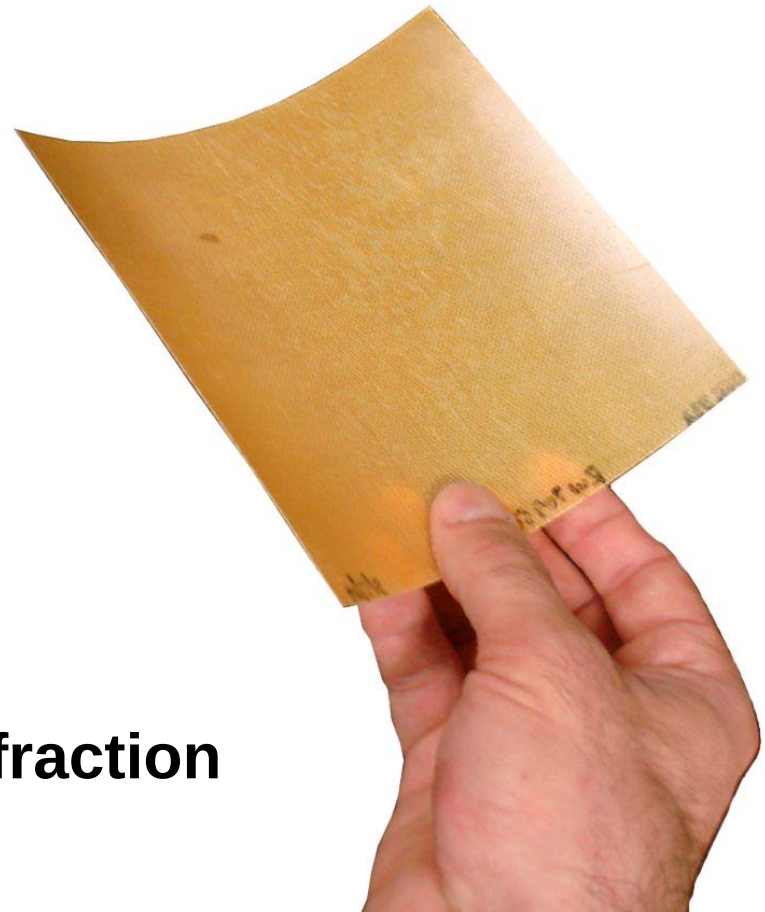


FAA 14 CFR 25.853 a-1

OSU Calorimeter - Single Ply Composites

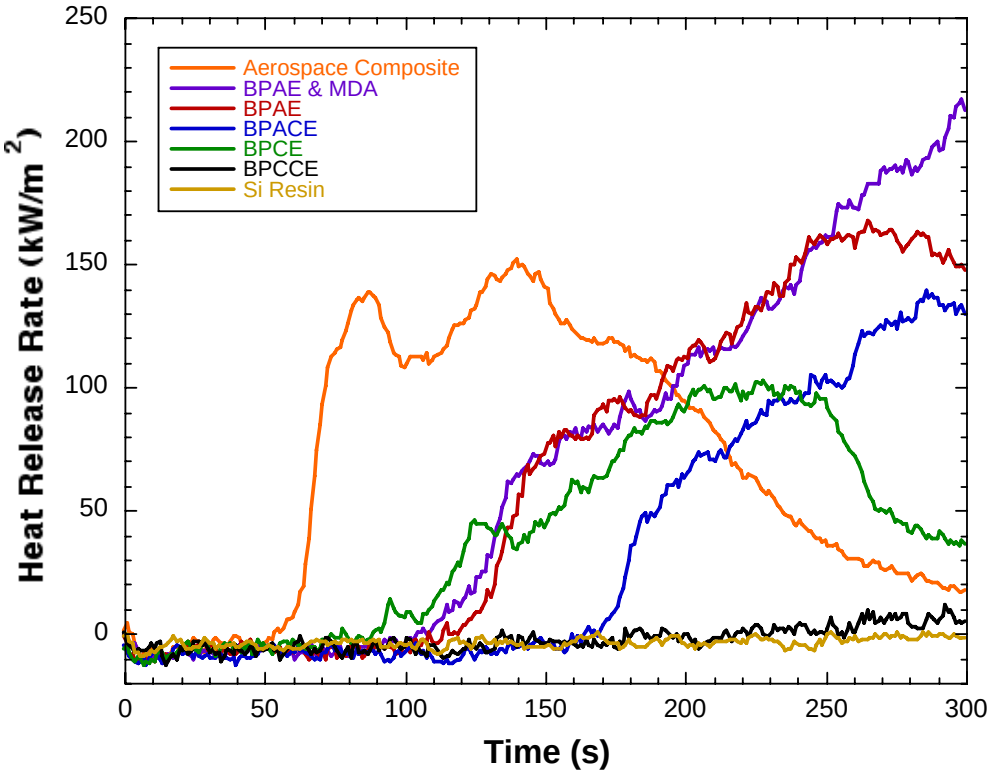


Resin	Peak HRR (kW/m2)	2-min Tot HR (kW/m2 min)	Char (%)
BPA Epoxy	111	44	1.9
BPAE + MDA	88	26	5.6
BPA CE	72	28	16.3
BPC Epoxy	48	28	14.1
Si Resin	33	12	NA
BPC CE	13	13	26.8



Char yield based on resin fraction

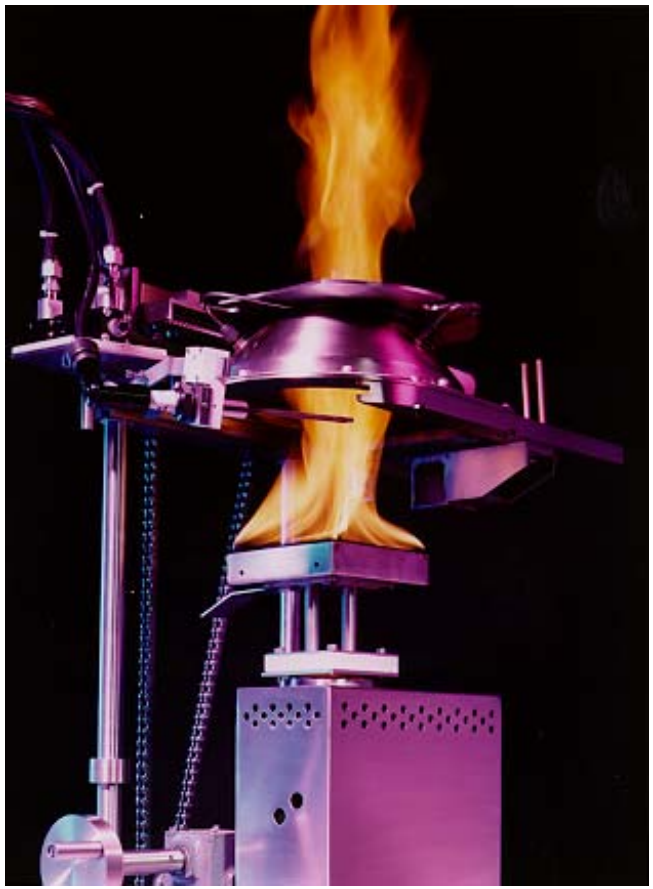
OSU Calorimeter - Multiple Ply Composites

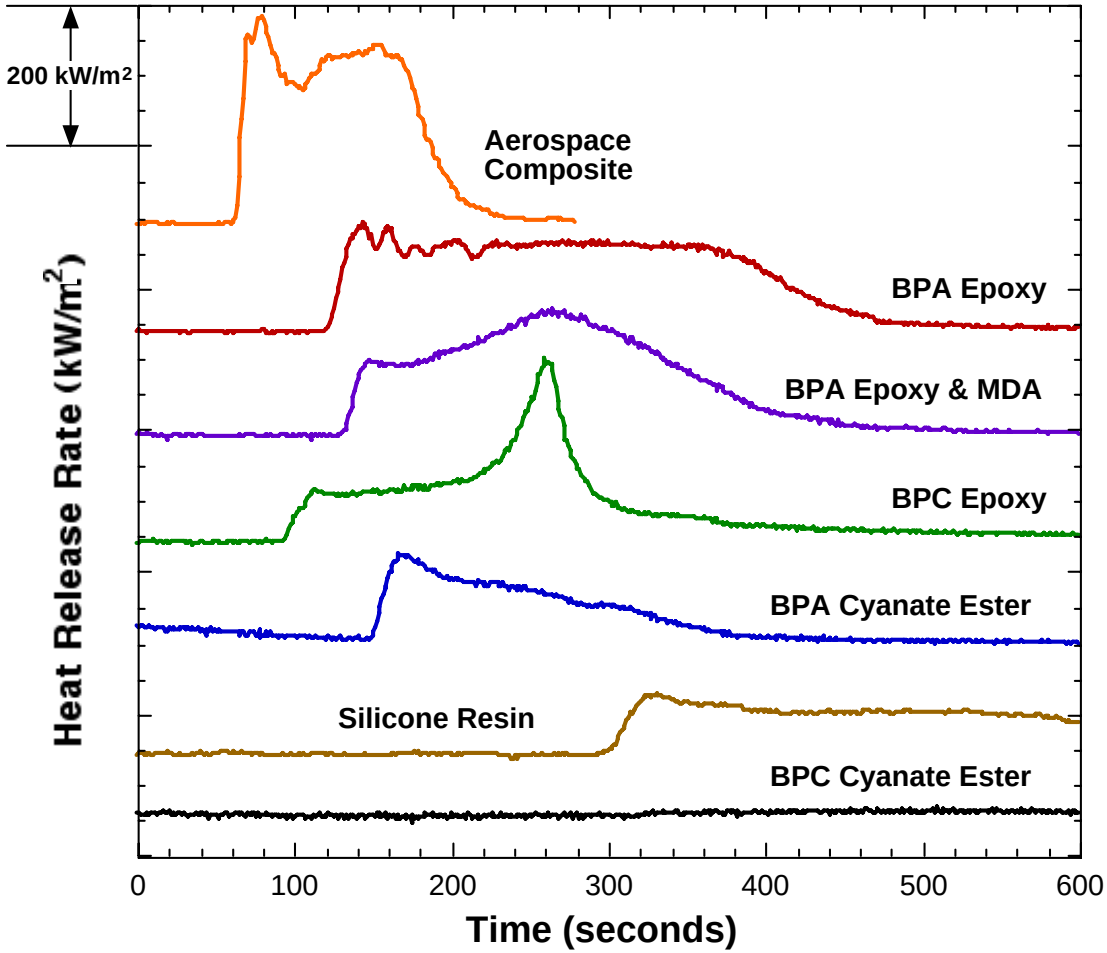


Test terminated at 5 min as per CFR 25.853 a-1

Resin	Peak HRR (kW/m2)	2-min Tot HR (kW-min/m2)	5-min Tot HR (kW-min/m2)
BPAE + MDA	216	-11	350
BPA Epoxy	168	-13	324
Aerospace Ep	146	83	342
BPA CE	139	-18	171
BPC Epoxy	102	-3	201
BPC CE	11	-13	-14
Si Resin	0	-0.6	-1

Cone Calorimeter - ASTM E 1354





- Samples tested at a 50 kW/m² incident heat flux
- HRR measured by oxygen consumption calorimetry

Cone Calorimeter Results

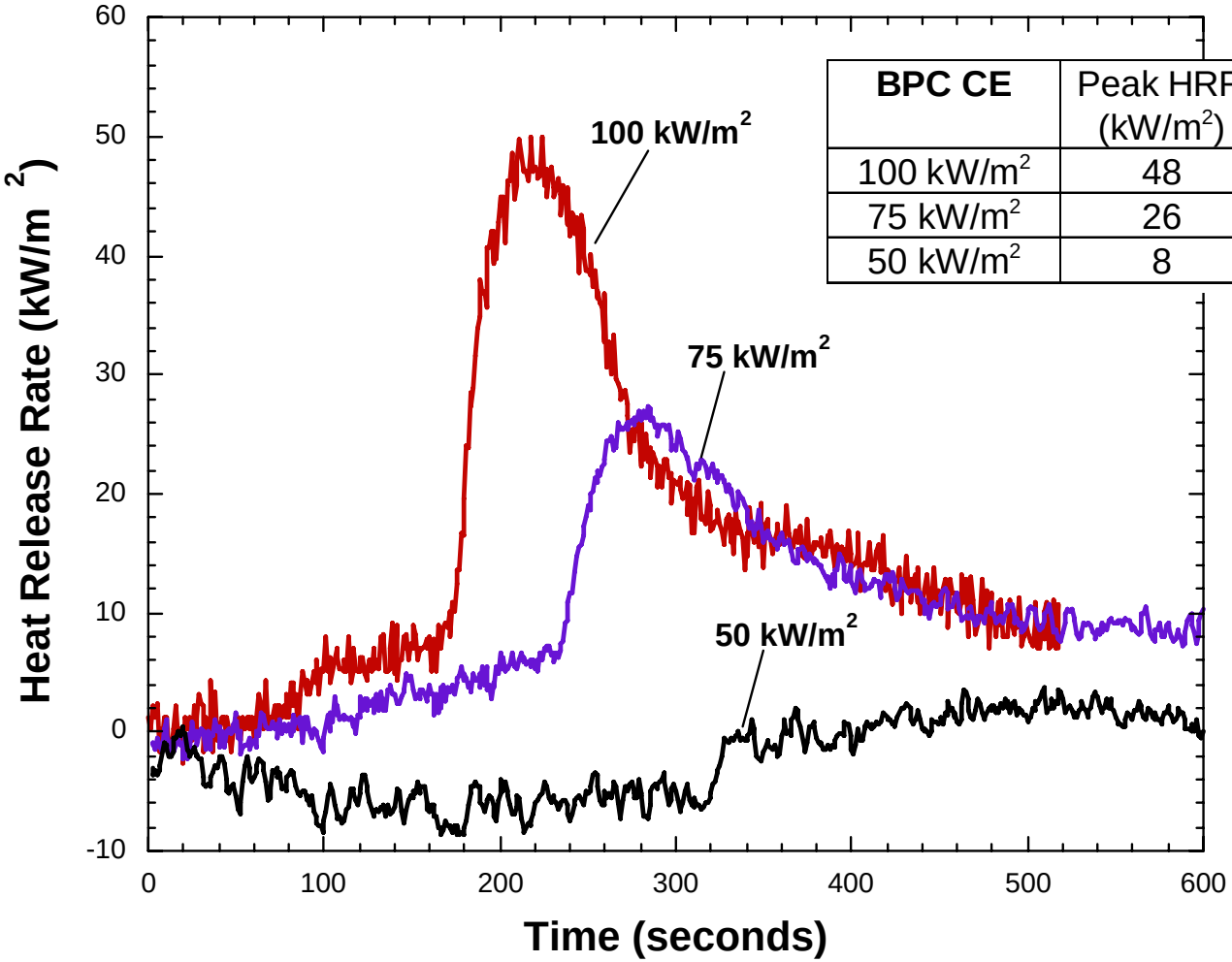
Resin	Cone Calorimeter at 50-kW/m^2 Irradiance				
	Peak HRR (kW/m^2)	Avg. HRR (kW/m^2)	Total HR (MJ/m^2)	t_{ig} (s)	Char* (%)
Aerospace Ep	302	182	29	61	NA
BPA Epoxy	155	78	36	102	25
BPA CE	118	24	13	129	52
BPAEp + MDA	107	78	34	110	40
BPC Epoxy	77	51	27	74	44
Si Resin	74	48	23	259	83
BPC CE	8	-2.4	0.3	NI	62

*Based on resin fraction of composite

- Peak HRR taken from first peak in HRR curve

- Average HRR taken from t_{ig} to flame out

BPCCE - MIL-STD-2031



BPC CE	Peak HRR (kW/m^2)	Avg. HRR (kW/m^2)	Total HR (MJ/m^2)	t_{ig} (s)
100 kW/m^2	48	23	6.5	145
75 kW/m^2	26	11	4.9	287
50 kW/m^2	8	-2.4	0.3	NI

- **Samples retained some strength after 100 kW/m^2 test**
- **BPCCE had lower HR at 100 kW/m^2 than others at 50 kW/m^2**

Conclusions

- **Flammability and mechanical properties of fiber-reinforced thermoset composites were evaluated**
- **High strengths can be achieved with fire-resistant resins**
- **Several resins have been identified that satisfy the flammability requirements for passenger aircraft and Navy ships**

Acknowledgements

- **MATERIALS**
  - **Vantico (formerly Ciba)** — **BPC Cyanate Ester**
  - **Lonza** — **BPA Cyanate Ester**
  - **Eikos** — **BPC Epoxy**
  - **Dow** — **BPA Epoxy**
  - **Dow Corning** — **Si Resin**

- **TESTING**
  - **Bob Filipczak** — **OSU Calorimeter Testing**
  - **Sean Crowley** — **Cone Calorimeter Testing**