

# FLAMMABILITY OF POLYMER COMPOSITES



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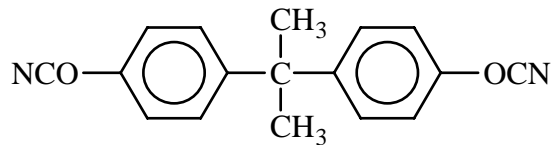
# Samples

**Bisphenol-A (BPA) Cyanate Ester & Epoxy**

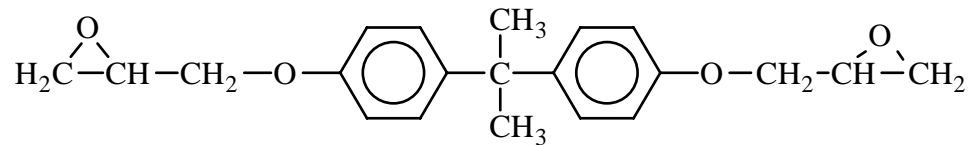
**Bisphenol-C (BPC) Cyanate Ester & Epoxy**

**Silicone Resin (Dow Corning)**

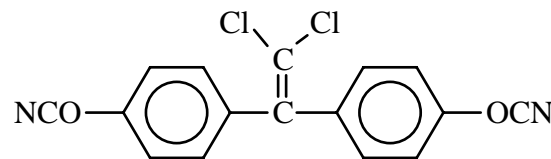
**Aerospace Epoxy Composite (Already Fabricated as Composite)**



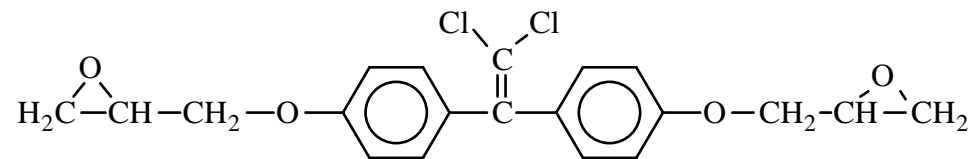
**BPACE**



**BPAE**



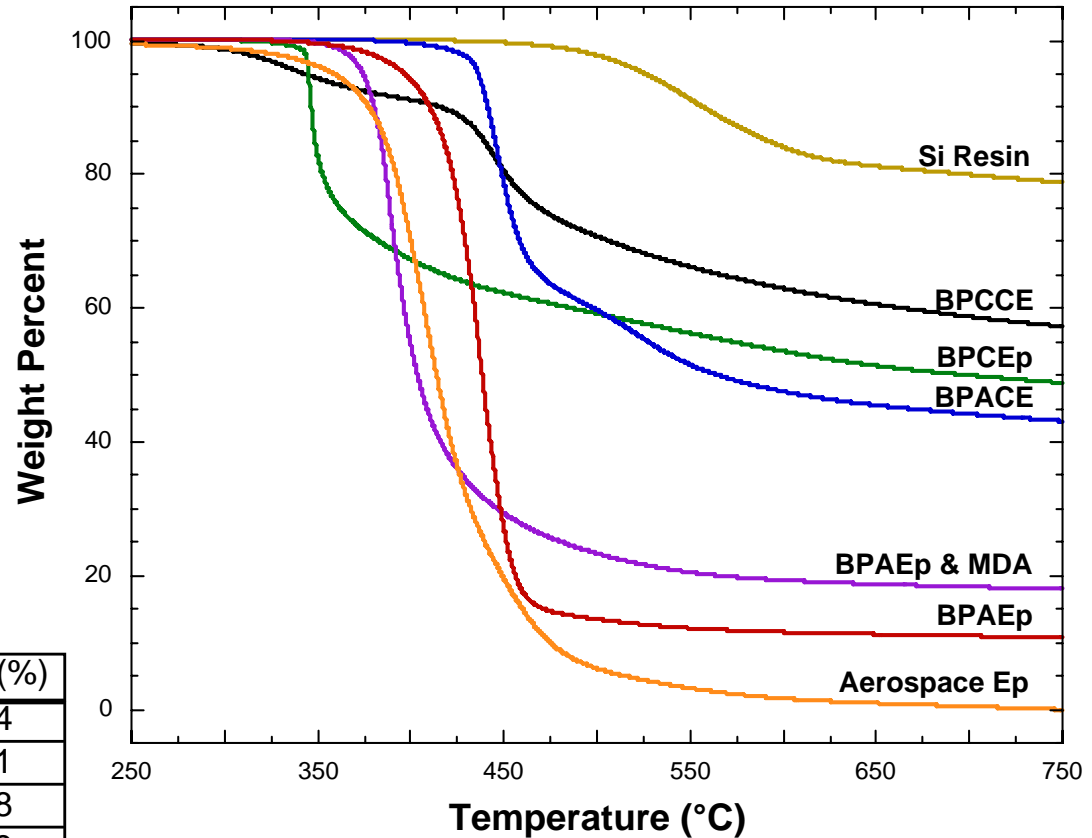
**BPCCE**



**BPCE**



# Thermogravimetric Analysis

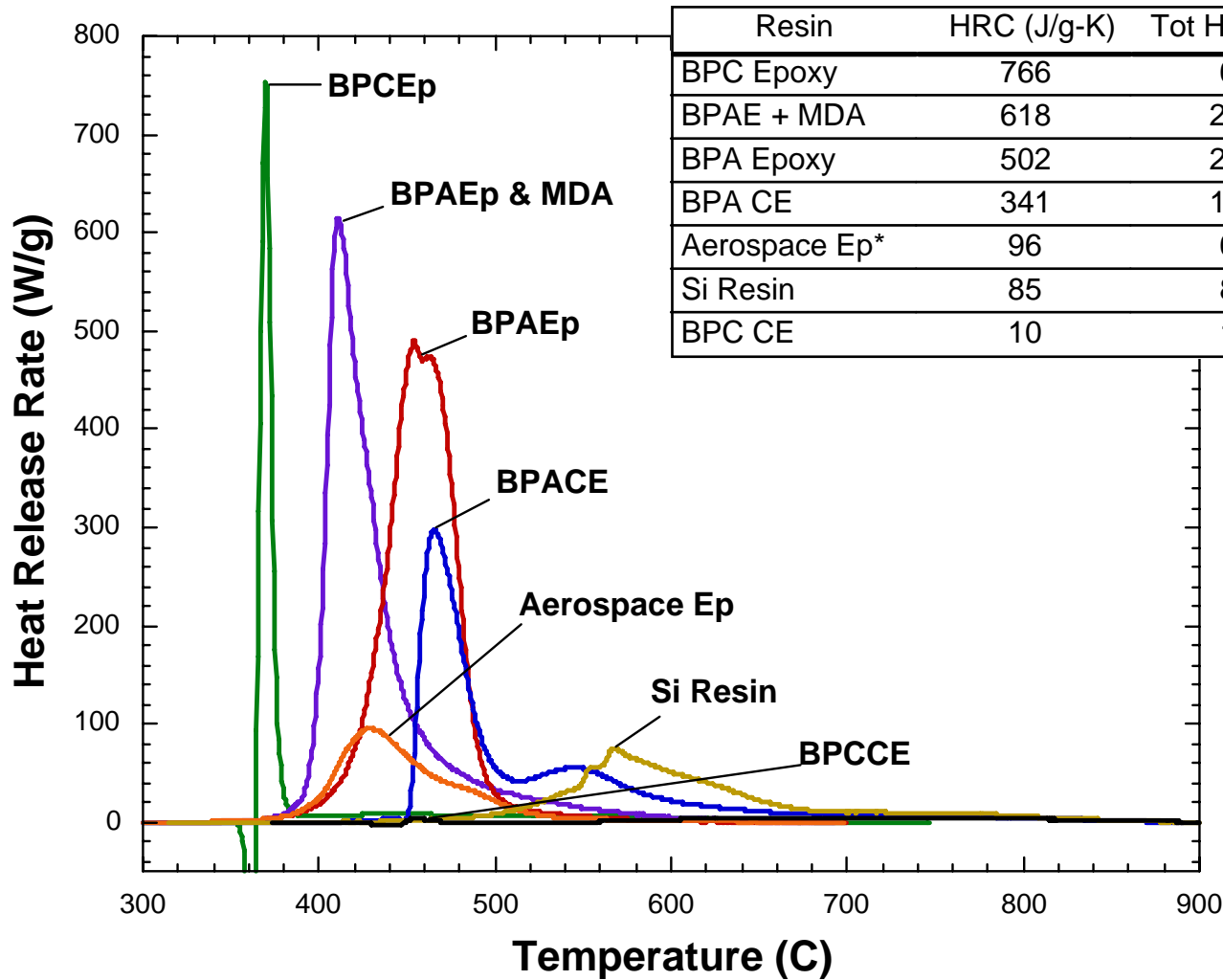


Resin	Onset (°C)	Tp (°C)	Char (%)
Si Resin	490	543	77.4
BPC CE	422	437	55.1
BPC Epoxy	342	345	46.8
BPA CE	428	440	41.9
BPAE + MDA	373	384	16.2
BPA Epoxy	411	432	9.5
Aerospace Ep*	374	403	73.3

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



# Microscale Combustion Calorimeter



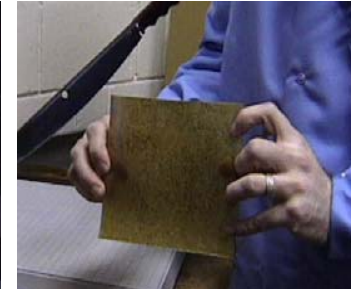
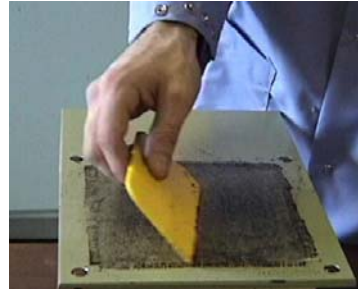
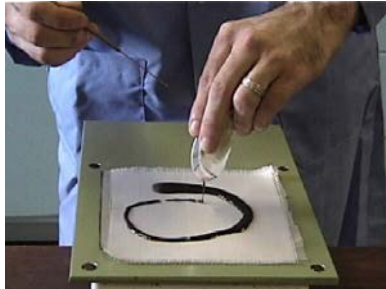
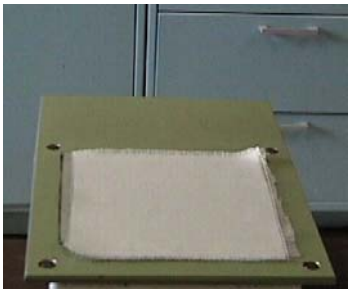
**ASTM D7309-07**



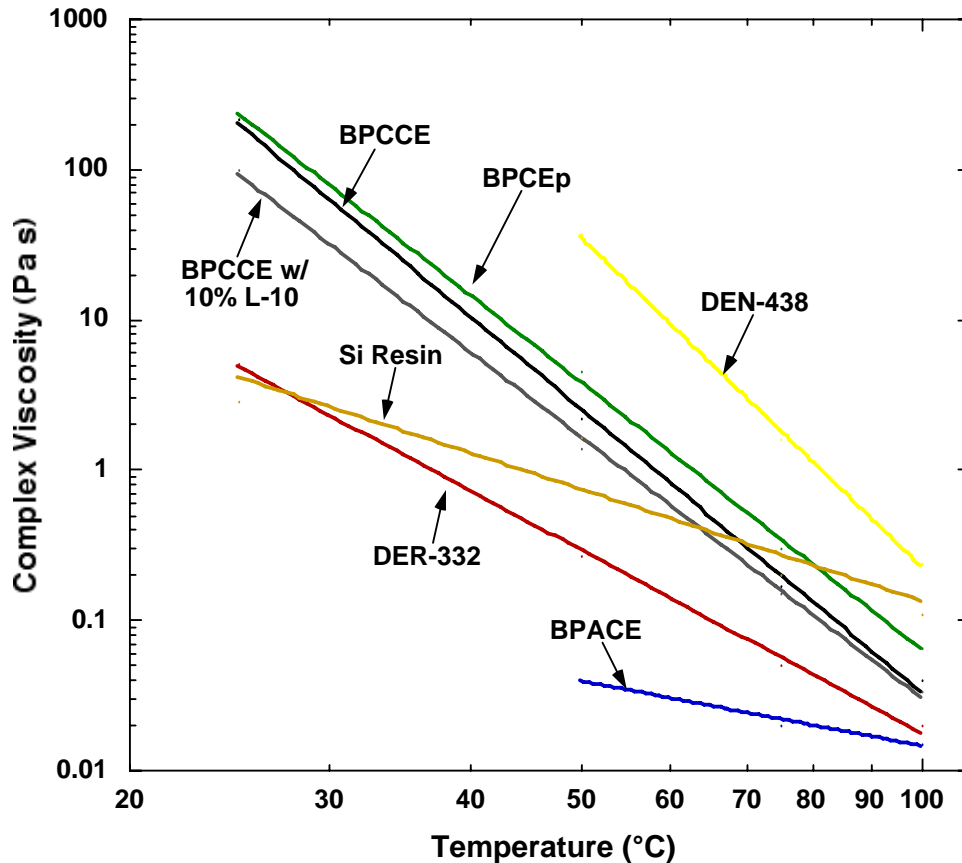


# Hand Lay-Up of Composites

- **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**



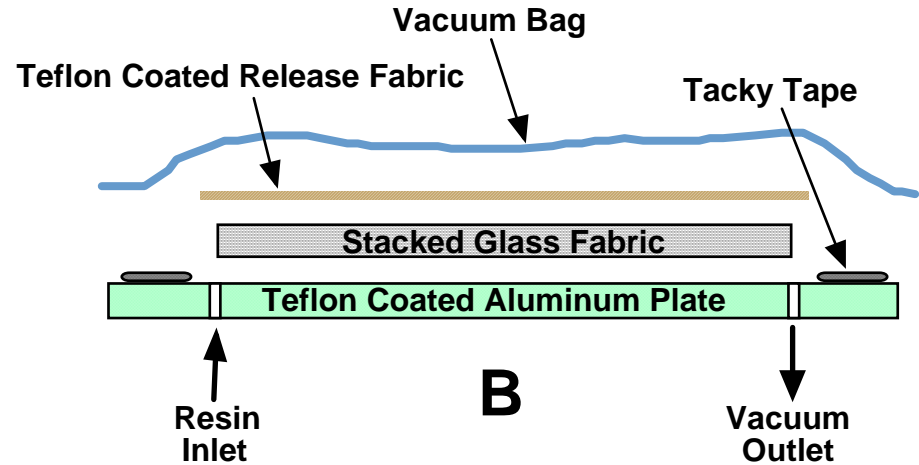
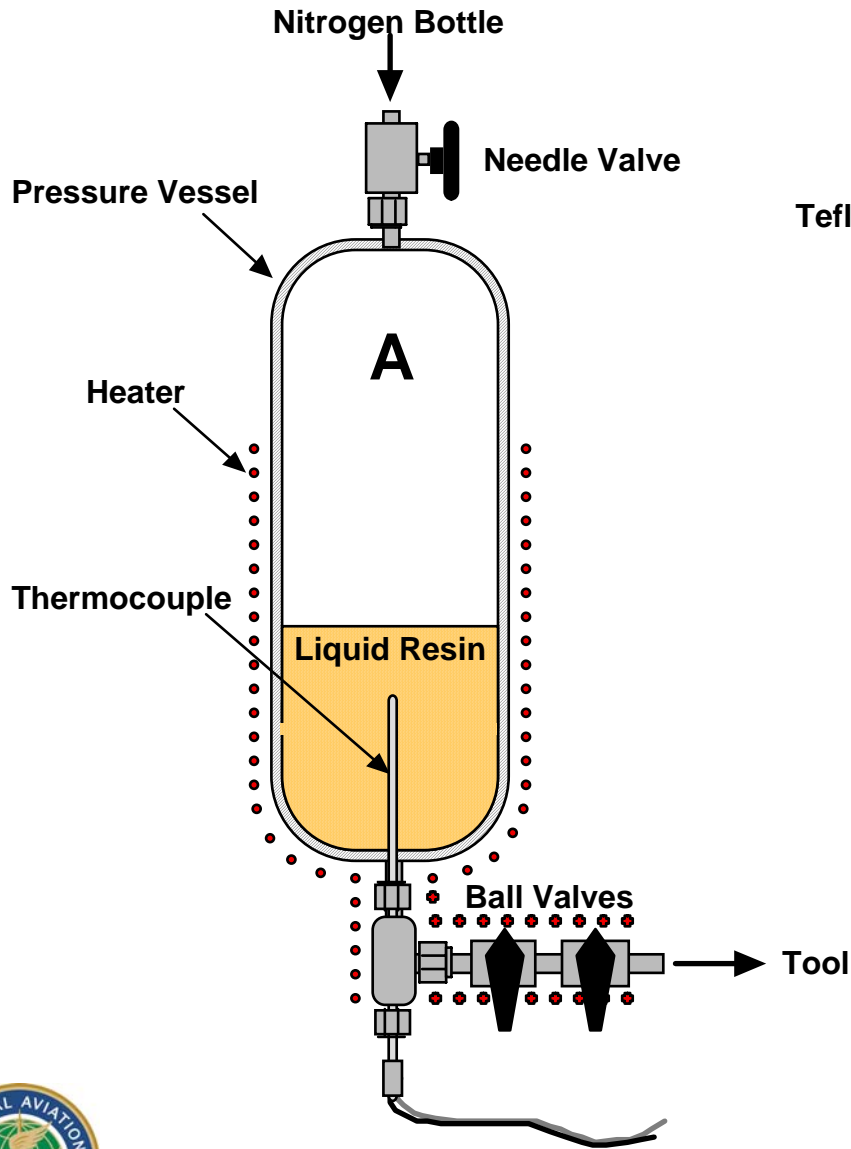
# Liquid Resin Viscosities



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

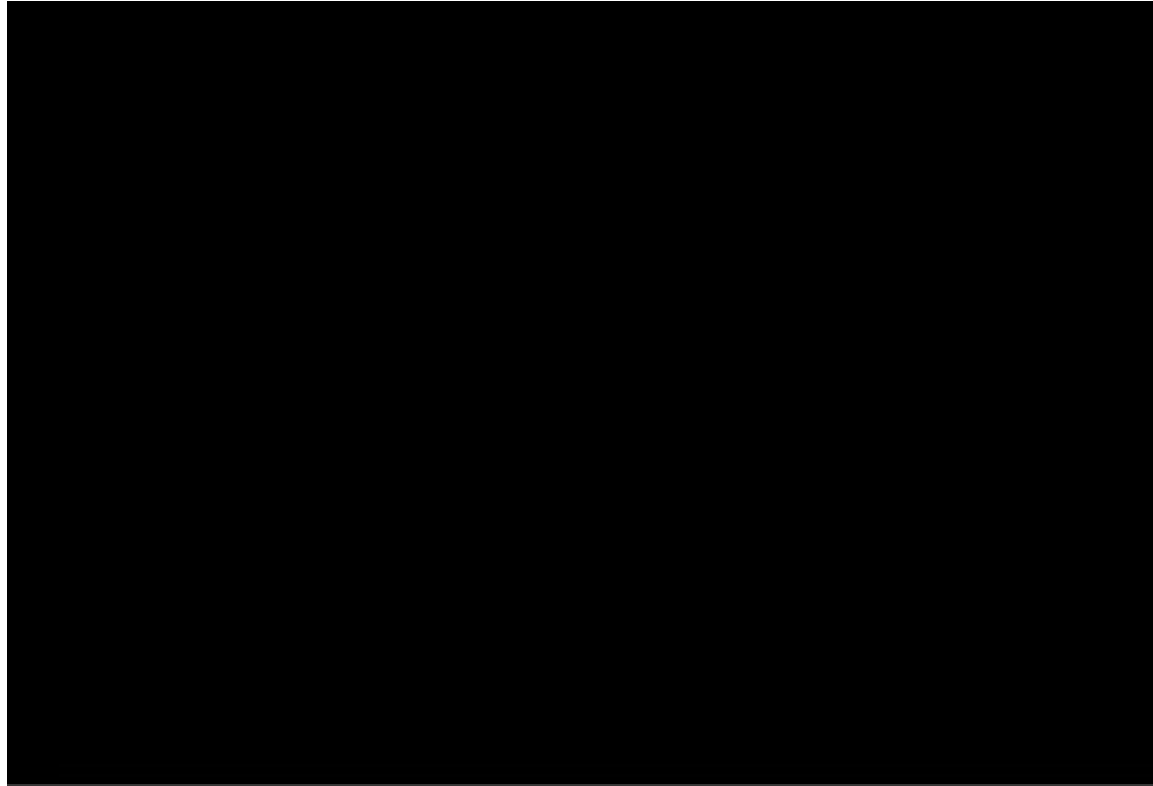


# VARTM Apparatus



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

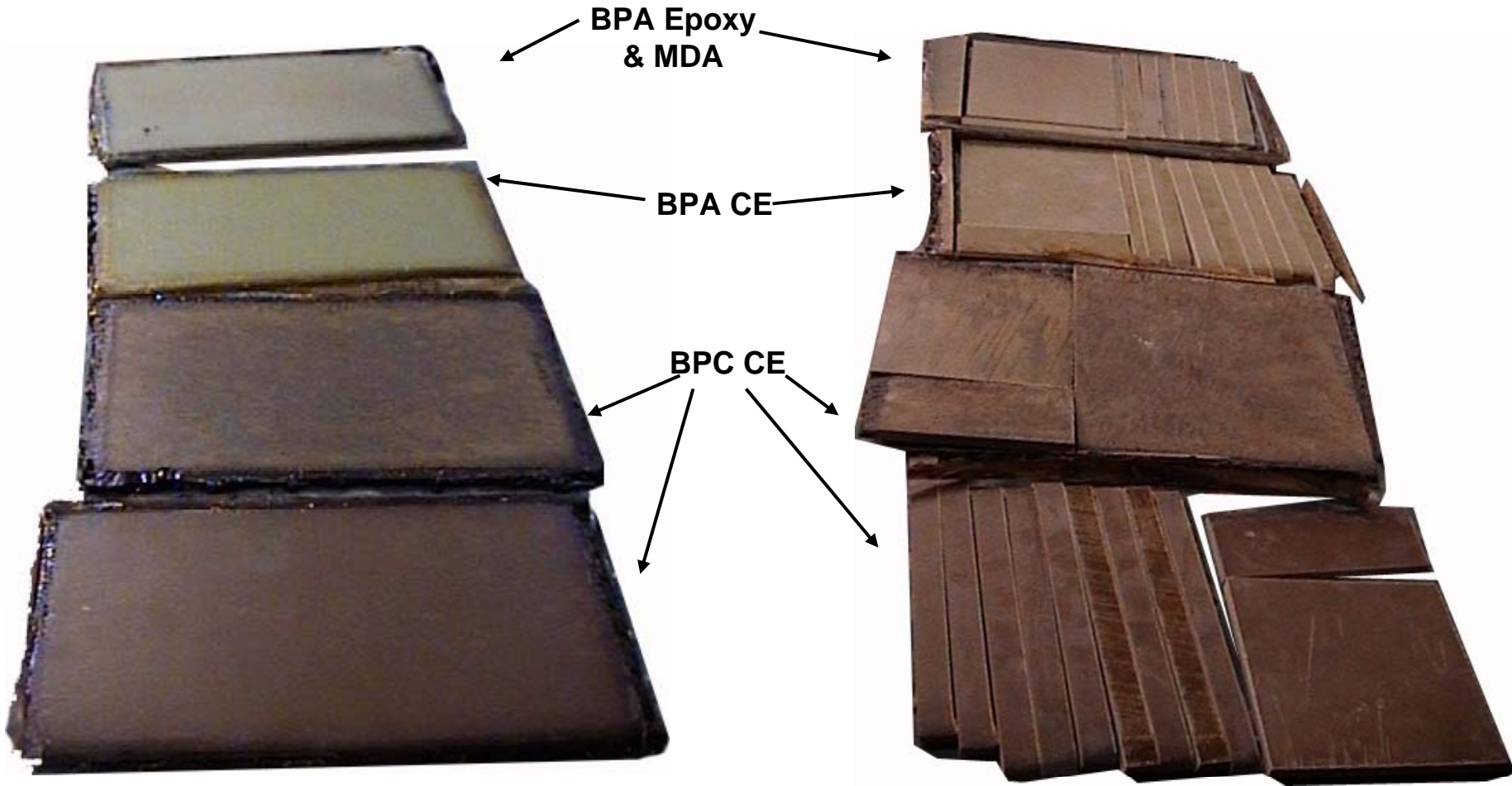
# Structural Composites



**Fabrication of Samples**



# Small VARTM Samples - 6" x 10"





# Large VARTM Samples - 14" x 14"

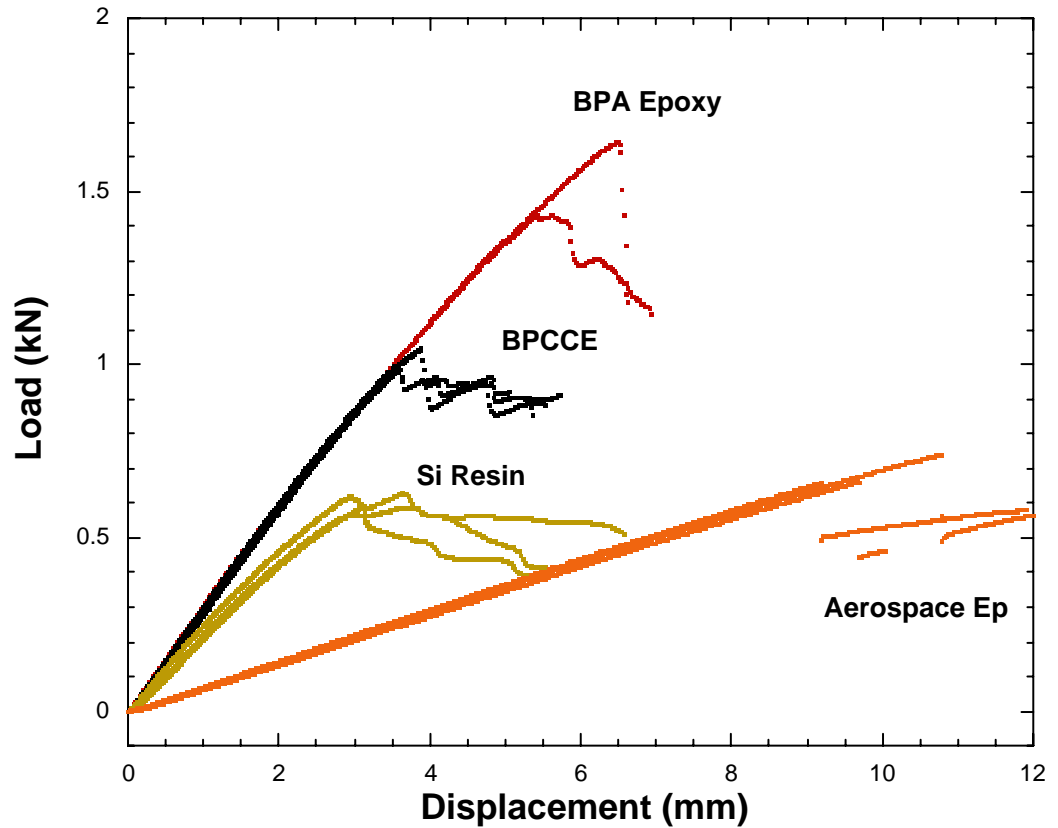
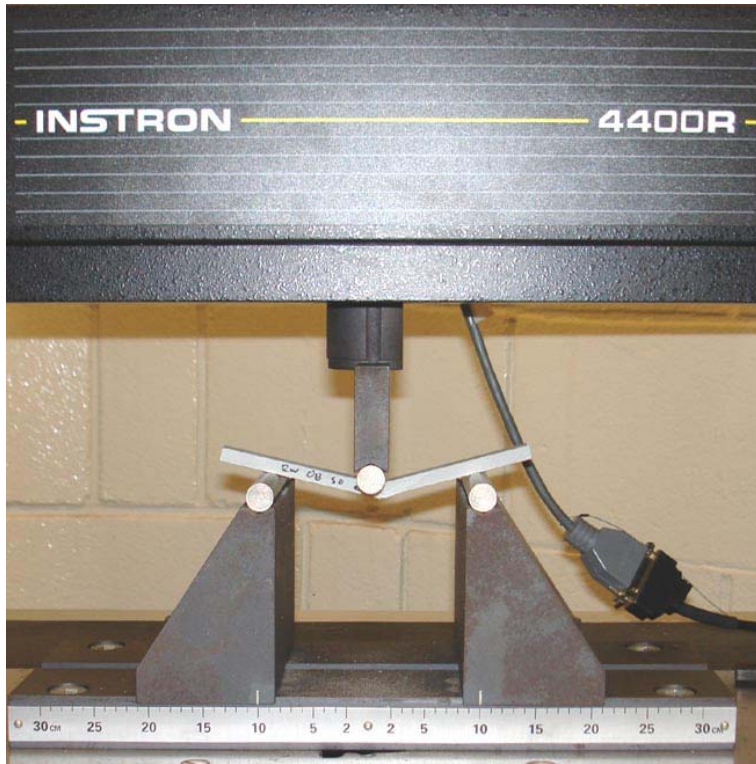
BPA Epoxy



BPC CE



# Mechanical Tests - ASTM D790



**Sample Dimensions:**

**150mm × 12.5mm × 6.4mm**  
Aerospace Epoxy (3mm)

**Span Length:**

**100mm**

**Crosshead Speed:**

**2.8mm/min**



# Mechanical Properties - 3 Point Flex Test

	Resin	Yield Stress (MPa)	Yield Strain (%)	Flexural Modulus (GPa)
16-Ply Quasi-Isotropic Carbon Fiber	<b>Aerospace Ep*</b>	800	1.8	47
	BPA Epoxy	620	2.3	29
18-Ply 8HS Weave Glass Fiber	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

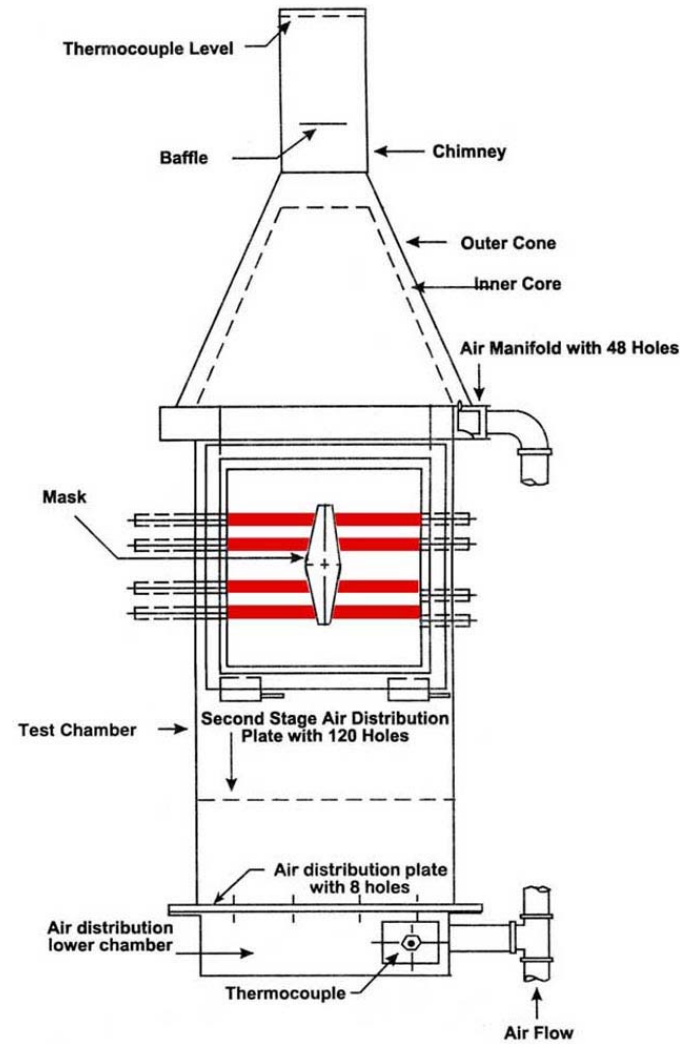
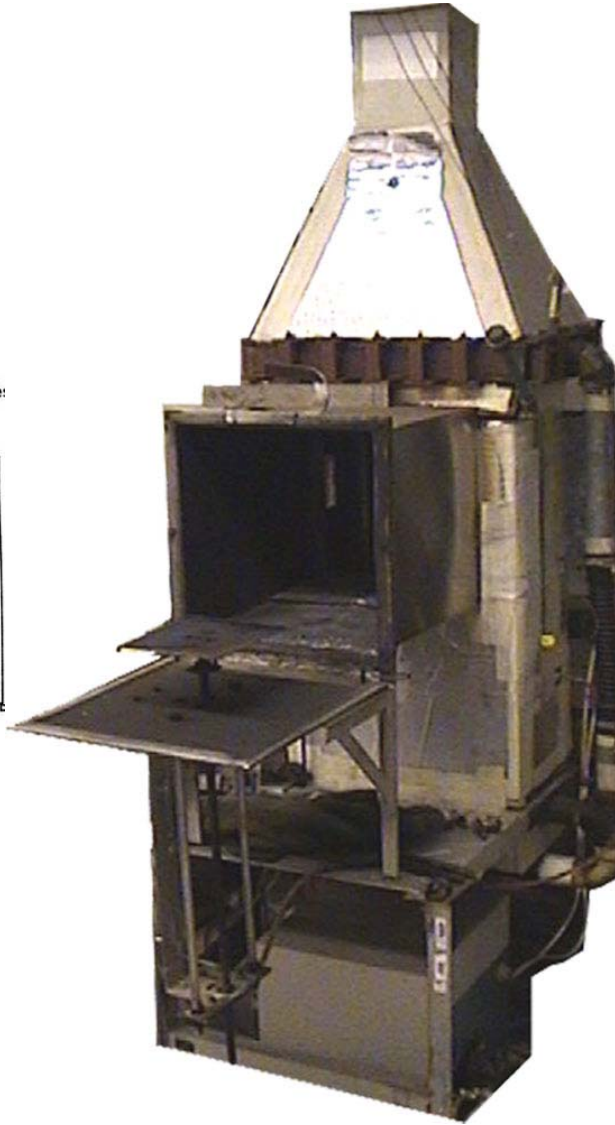
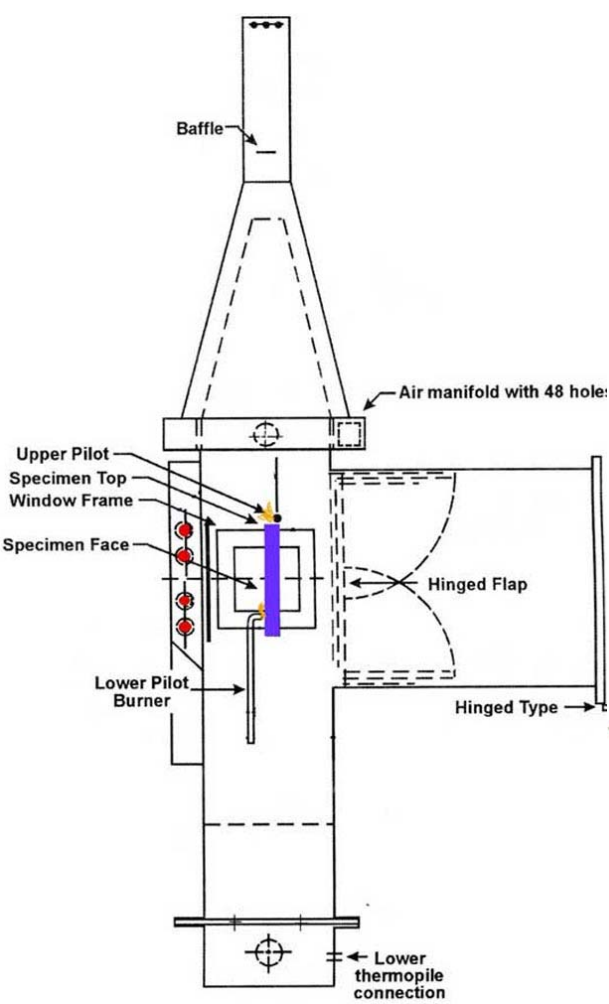
\*\*Result from a single test due to a limited amount of sample

- Resin-rich BPC Epoxy failed by shear
- All other samples failed by tension/compression



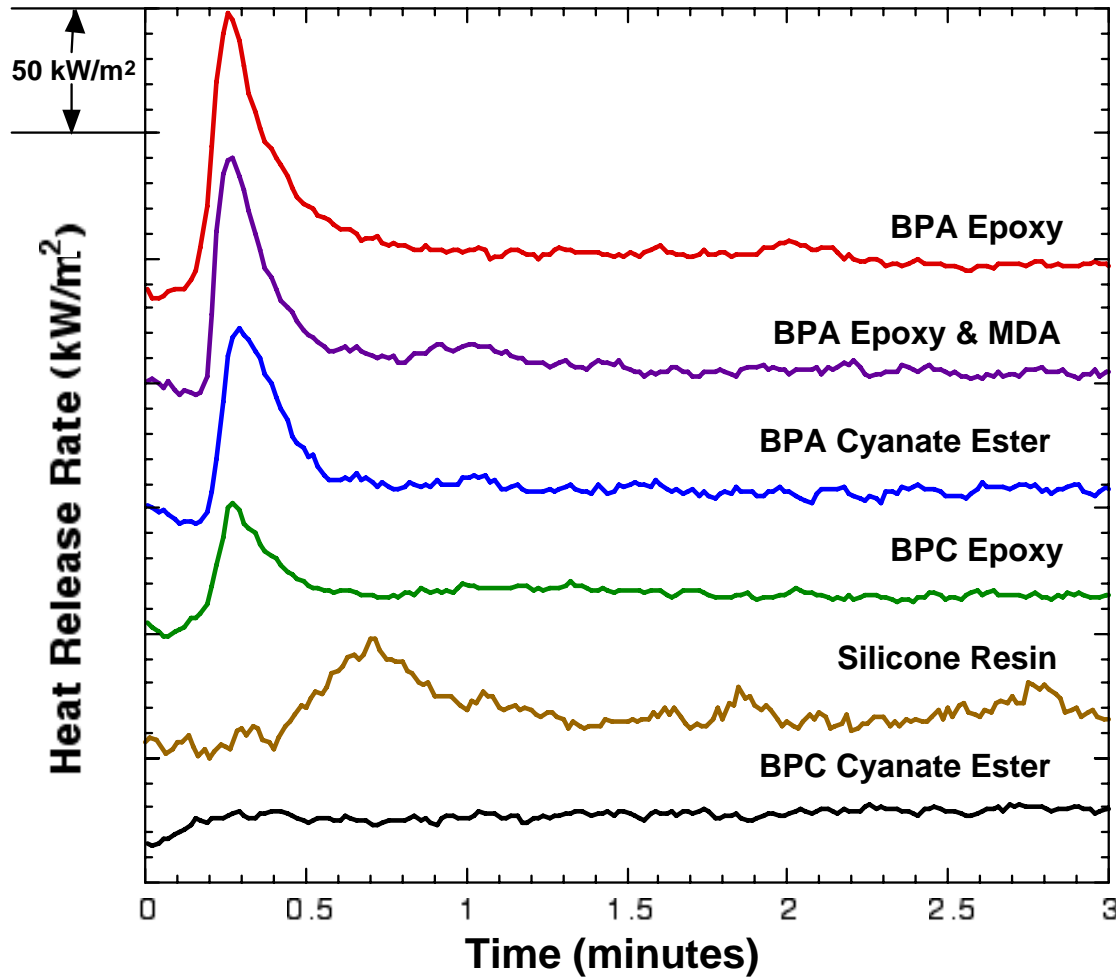


# OSU Calorimeter

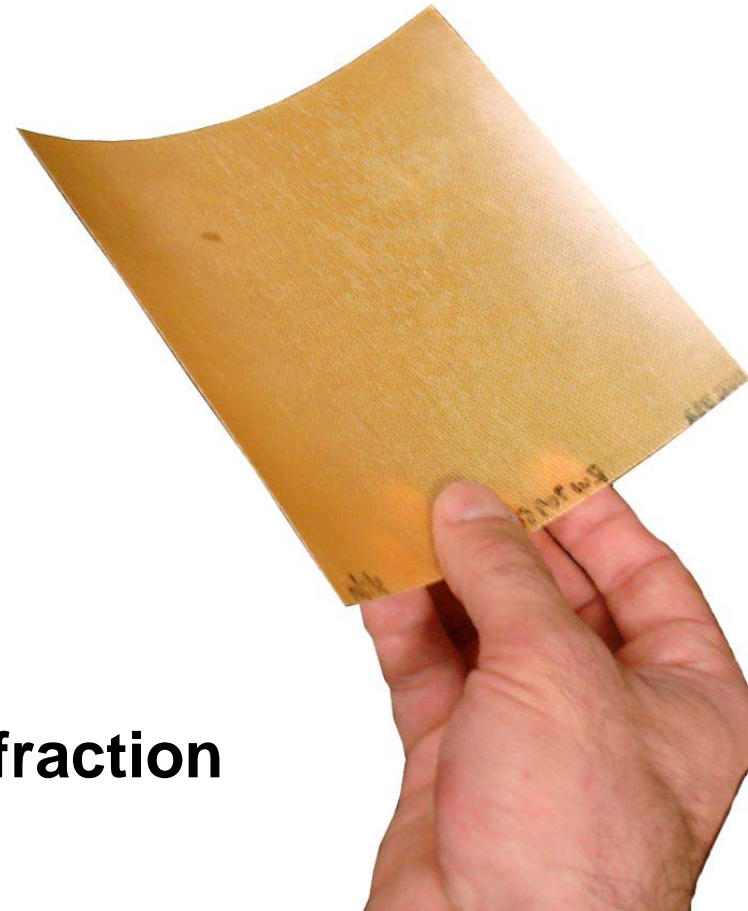


**FAA 14 CFR 25.853 a-1**

# OSU Calorimeter - Single Ply Composites



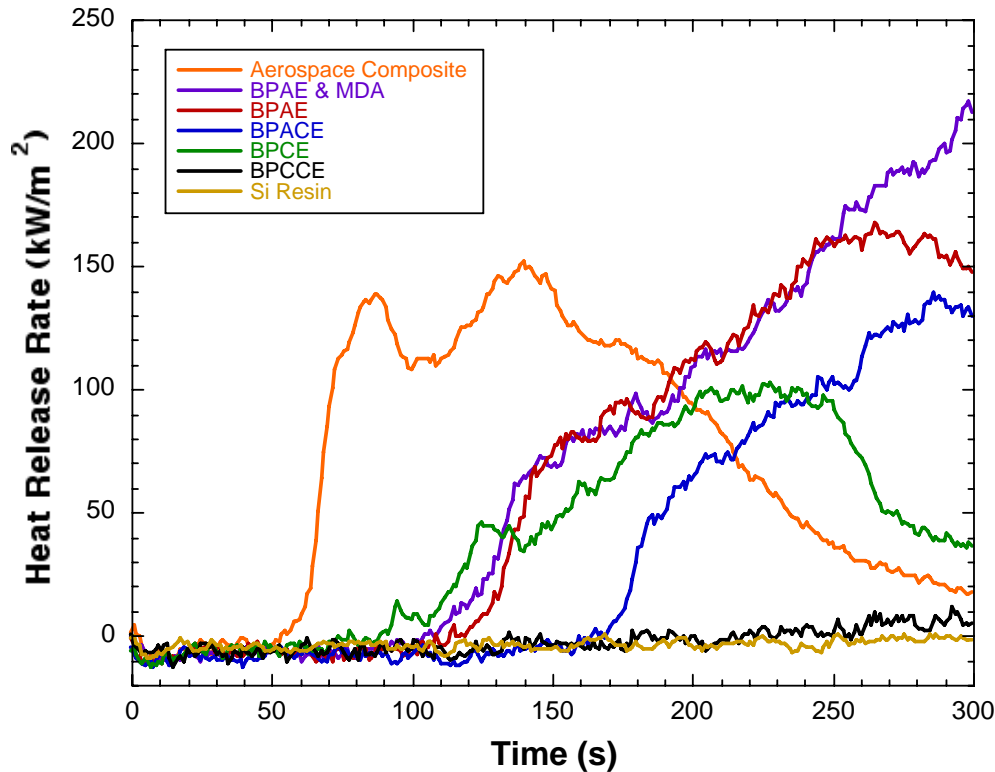
Resin	Peak HRR (kW/m <sup>2</sup> )	2-min Tot HR (kW/m <sup>2</sup> min)	Char (%)
BPA Epoxy	111	44	1.9
BPAE + MDA	88	26	5.6
BPA CE	72	28	16.3
BPC Epoxy	48	28	14.1
Si Resin	33	12	NA
BPC CE	13	13	26.8



**Char yield based on resin fraction**



# OSU Calorimeter - Multiple Ply Composites

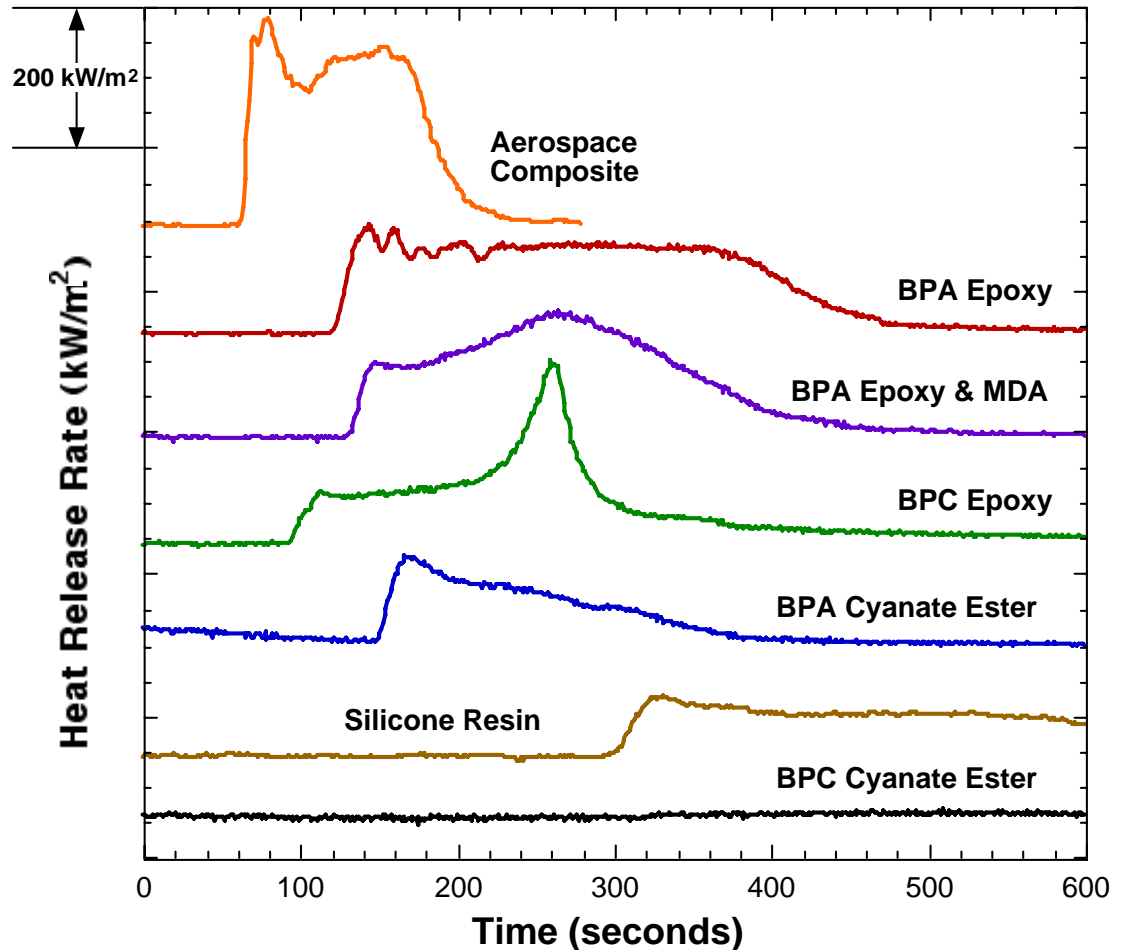
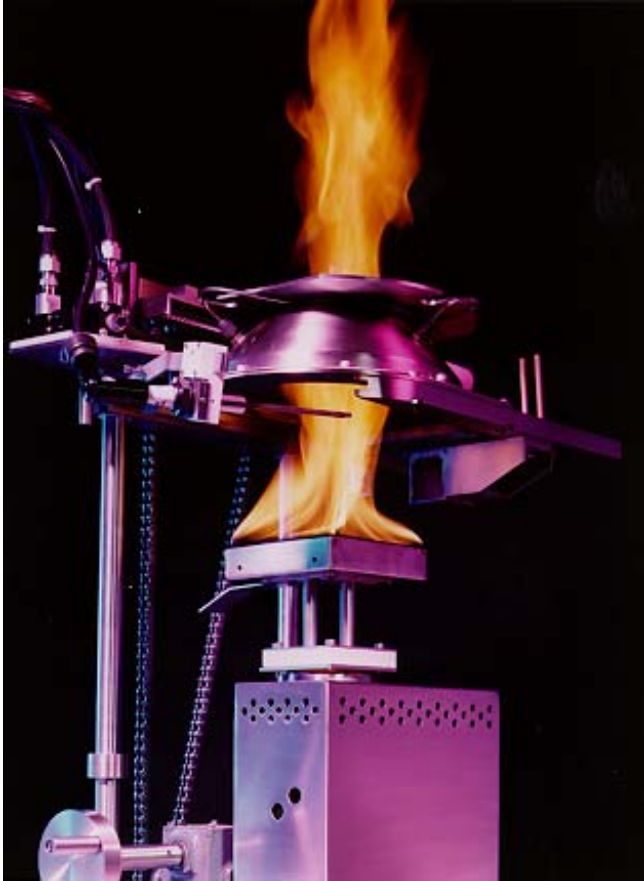


**Test terminated at 5 min as per  
CFR 25.853 a-1**

Resin	Peak HRR (kW/m <sup>2</sup> )	2-min Tot HR (kW-min/m <sup>2</sup> )	5-min Tot HR (kW-min/m <sup>2</sup> )
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/m<sup>2</sup> incident heat flux
- HRR measured by oxygen consumption calorimetry



# Cone Calorimeter Results

Resin	Cone Calorimeter at 50-kW/m <sup>2</sup> Irradiance				
	Peak HRR (kW/m <sup>2</sup> )	Avg. HRR (kW/m <sup>2</sup> )	Total HR (MJ/m <sup>2</sup> )	t <sub>ig</sub> (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

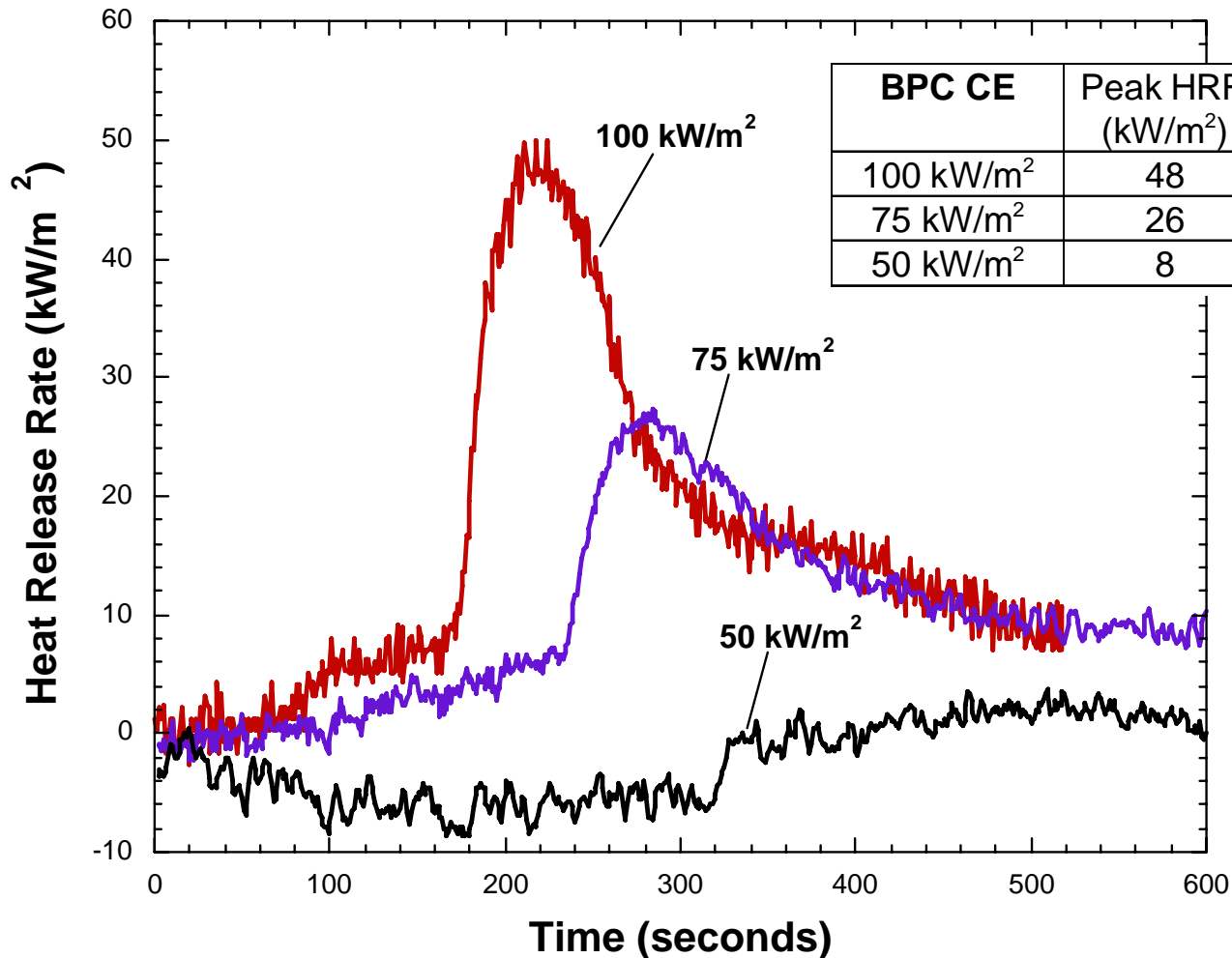
\*Based on resin fraction of composite

- Peak HRR taken from first peak in HRR curve
- Average HRR taken from t<sub>ig</sub> to flame out





# BPCCE - MIL-STD-2031



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



# 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**

