Aeroplastics™

Reduction in Heat Transfer of Structural Polymers

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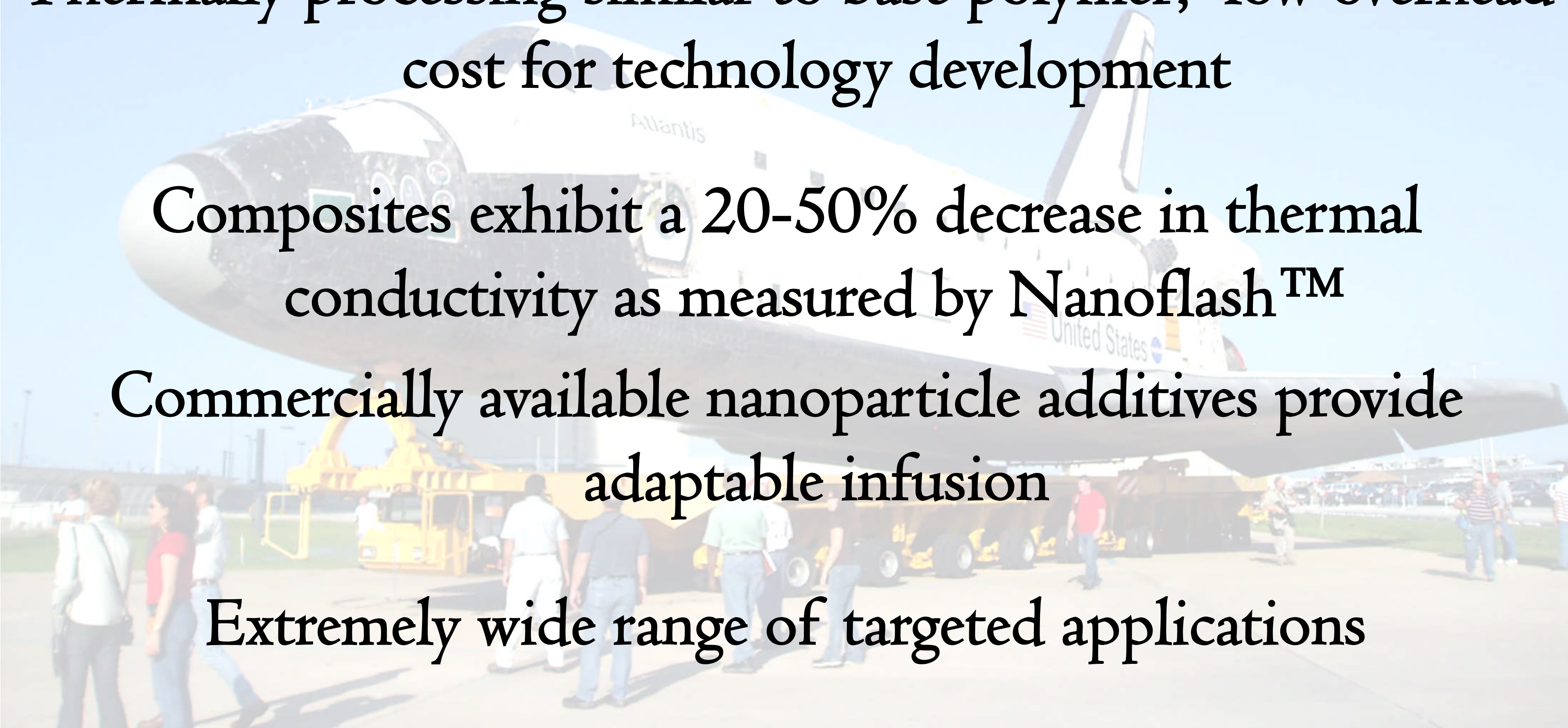
Presentation for Sharing with Technology Transfer Evaluation Partners

AeroPlastics™



Aerogel infused thermoplastic polymers

Thermally processing similar to base polymer; low overhead cost for technology development

Composites exhibit a 20-50% decrease in thermal conductivity as measured by Nanoflash™

Commercially available nanoparticle additives provide adaptable infusion

Extremely wide range of targeted applications

Thermal Processing

Aerogel meet Polymer

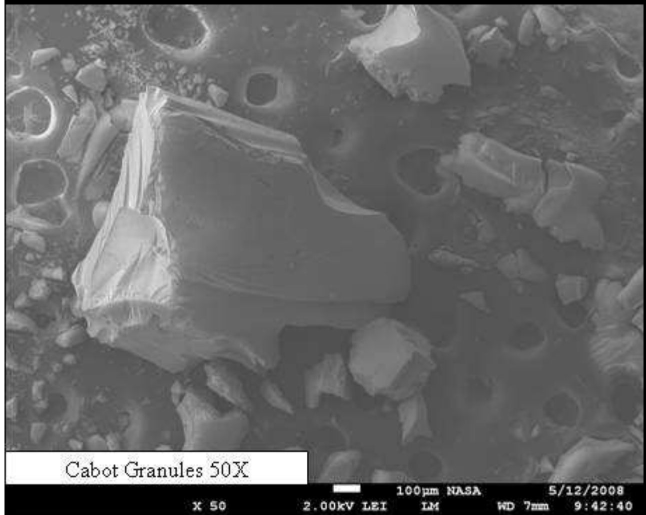
Cabot Nanogel

Beads
Granules
Fine particles

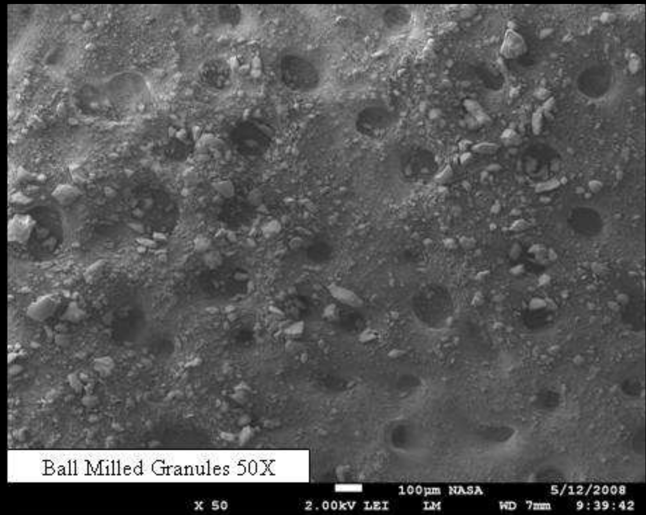
Polymer Pellets

•Polyolefins
•Nylons
•Polyetherimides

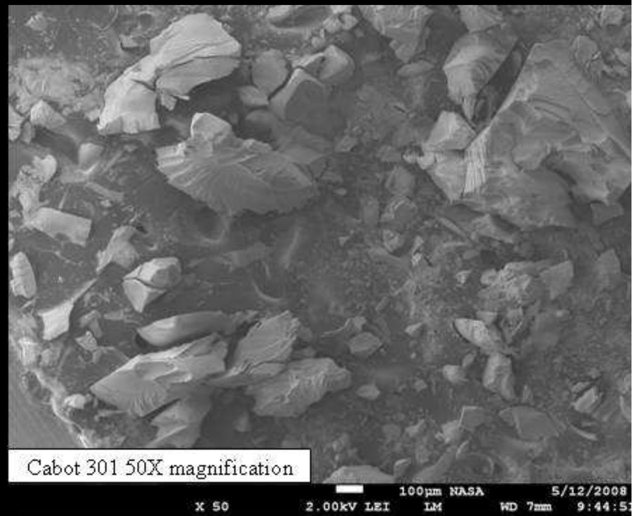
Types of Aerogel



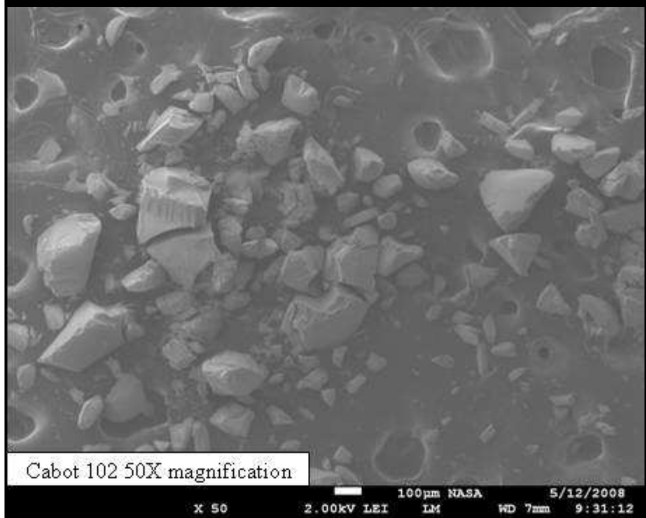
Cabot Granules 50X



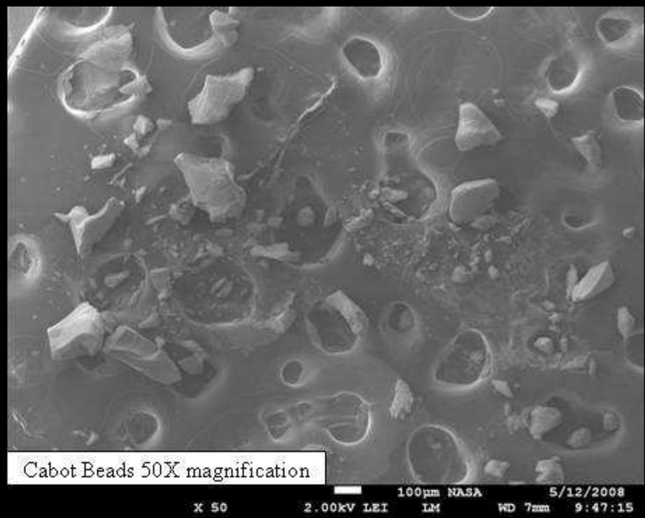
Ball Milled Granules 50X



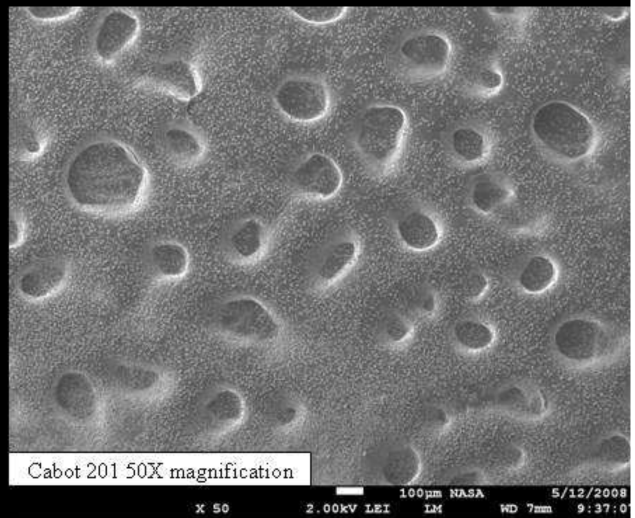
Cabot 301 50X magnification



Cabot 102 50X magnification



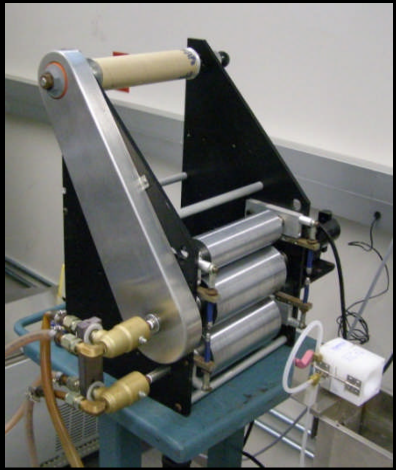
Cabot Beads 50X magnification

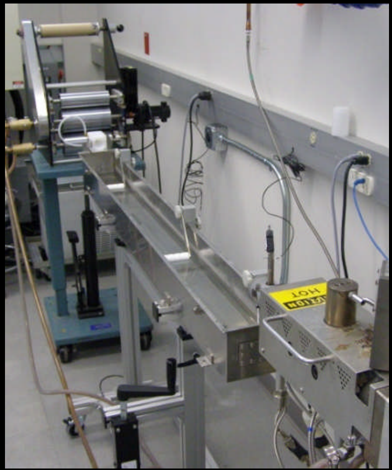


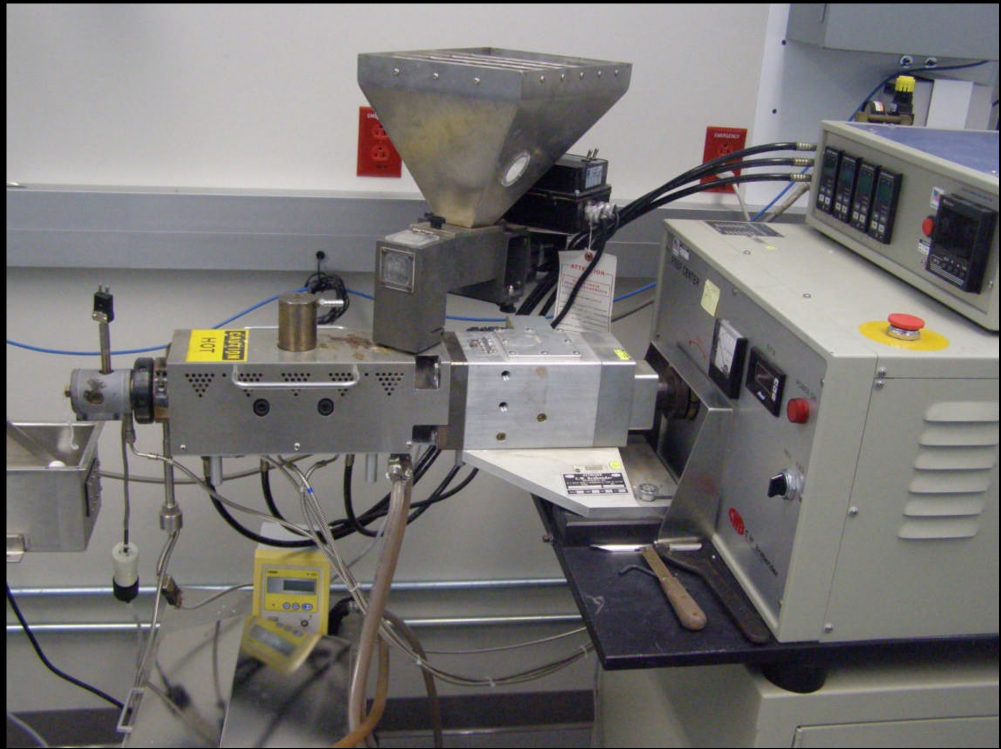
Cabot 201 50X magnification

Thermal Compounding and Processing

Twin Screw Extruder

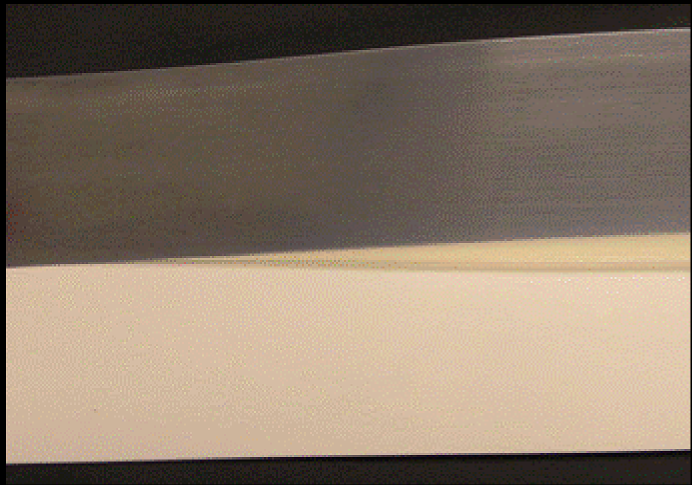




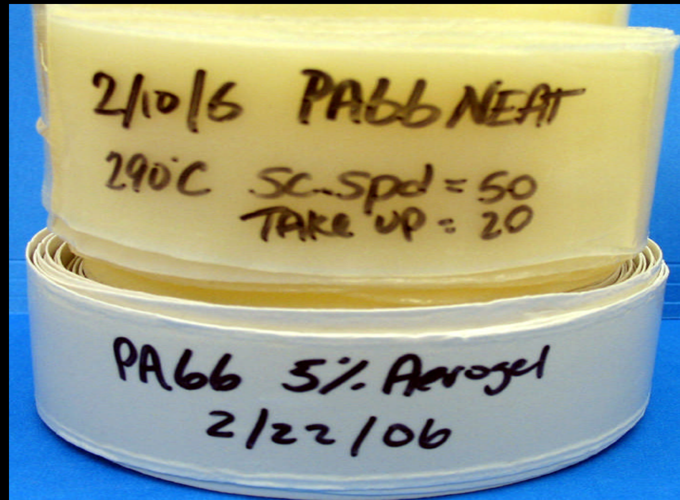


Ribbons (2” & 6”), Rope, Wire coating, and Tubing dies

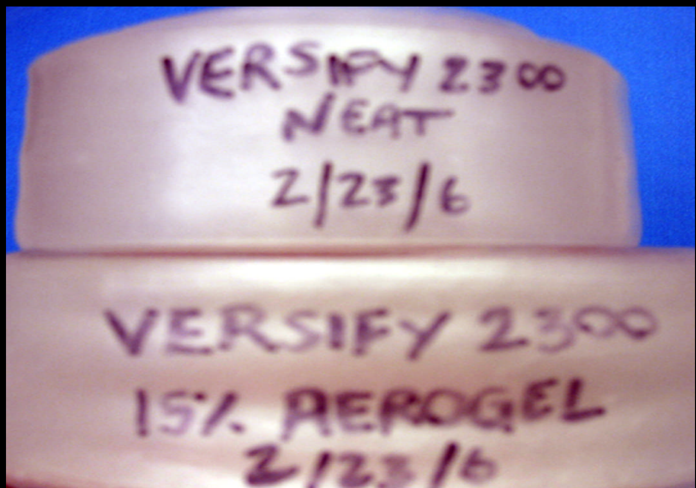
Aeroplastic Tapes



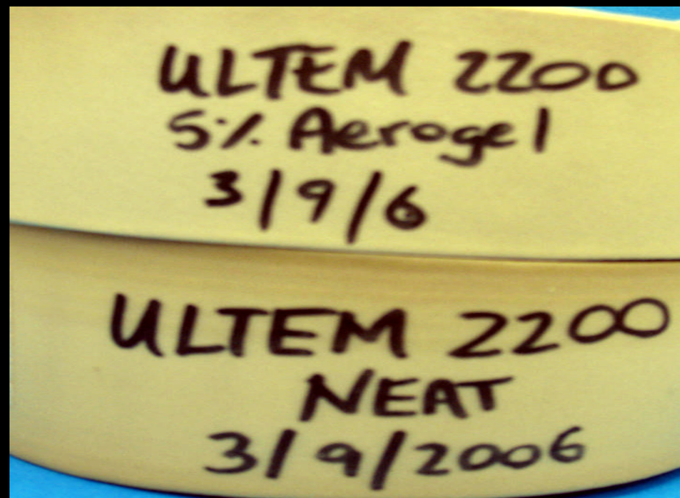
MXD6



PA66



Versify 2300



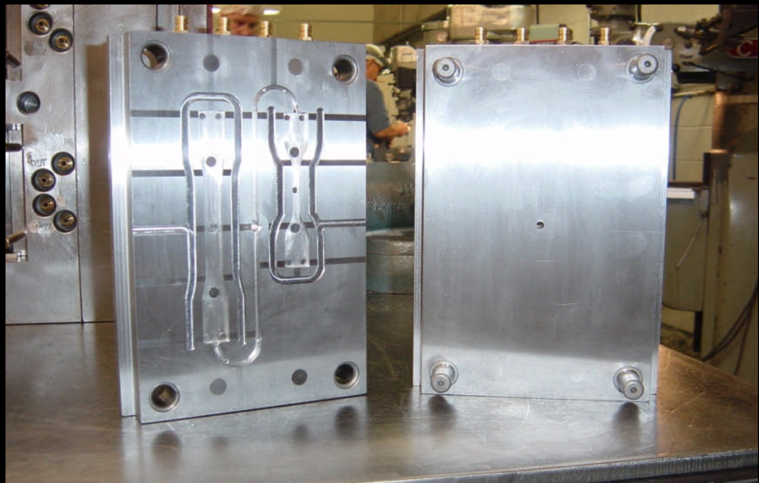
Ultem

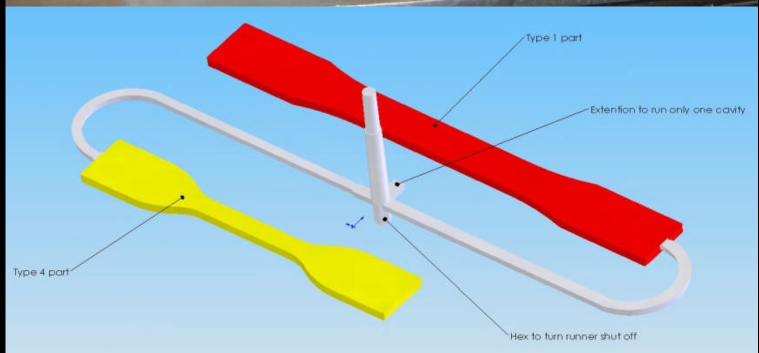
Thermal Processing

50 Ton Injection Molder

Fabrication parts up to 1.9 oz at a maximum of 1 part/20 sec.

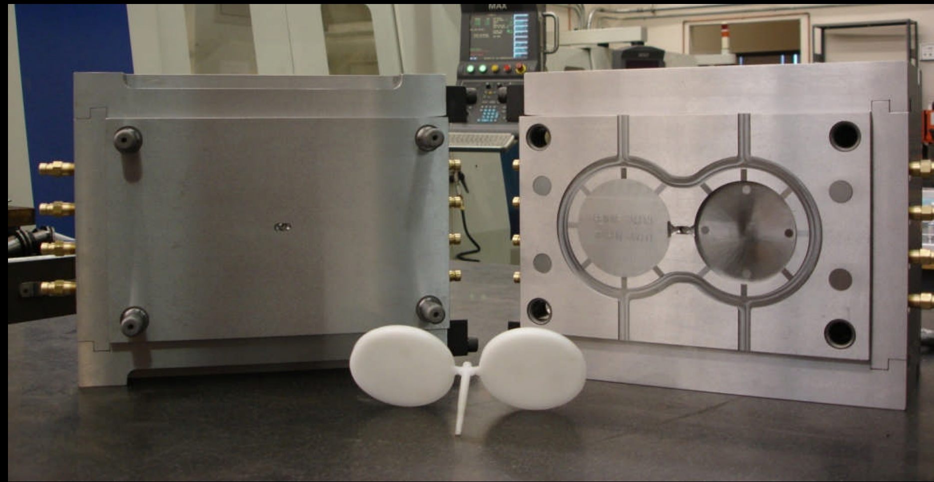
AeroPlastic Test Articles



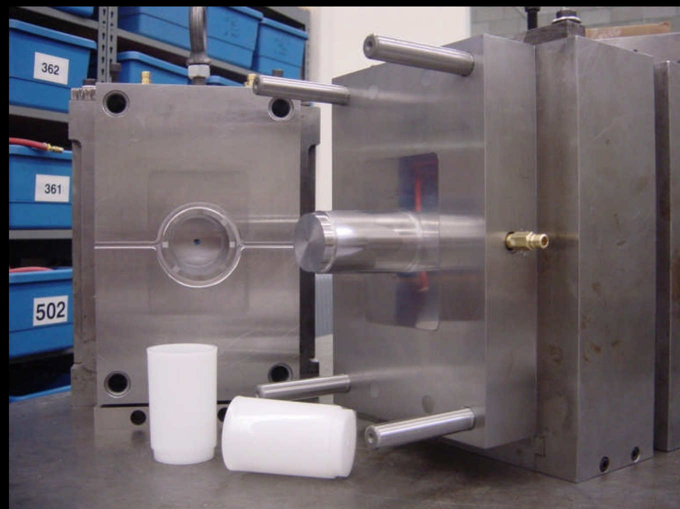


Tensile Test Samples: ASTM D638

Fire Test Samples: UL94

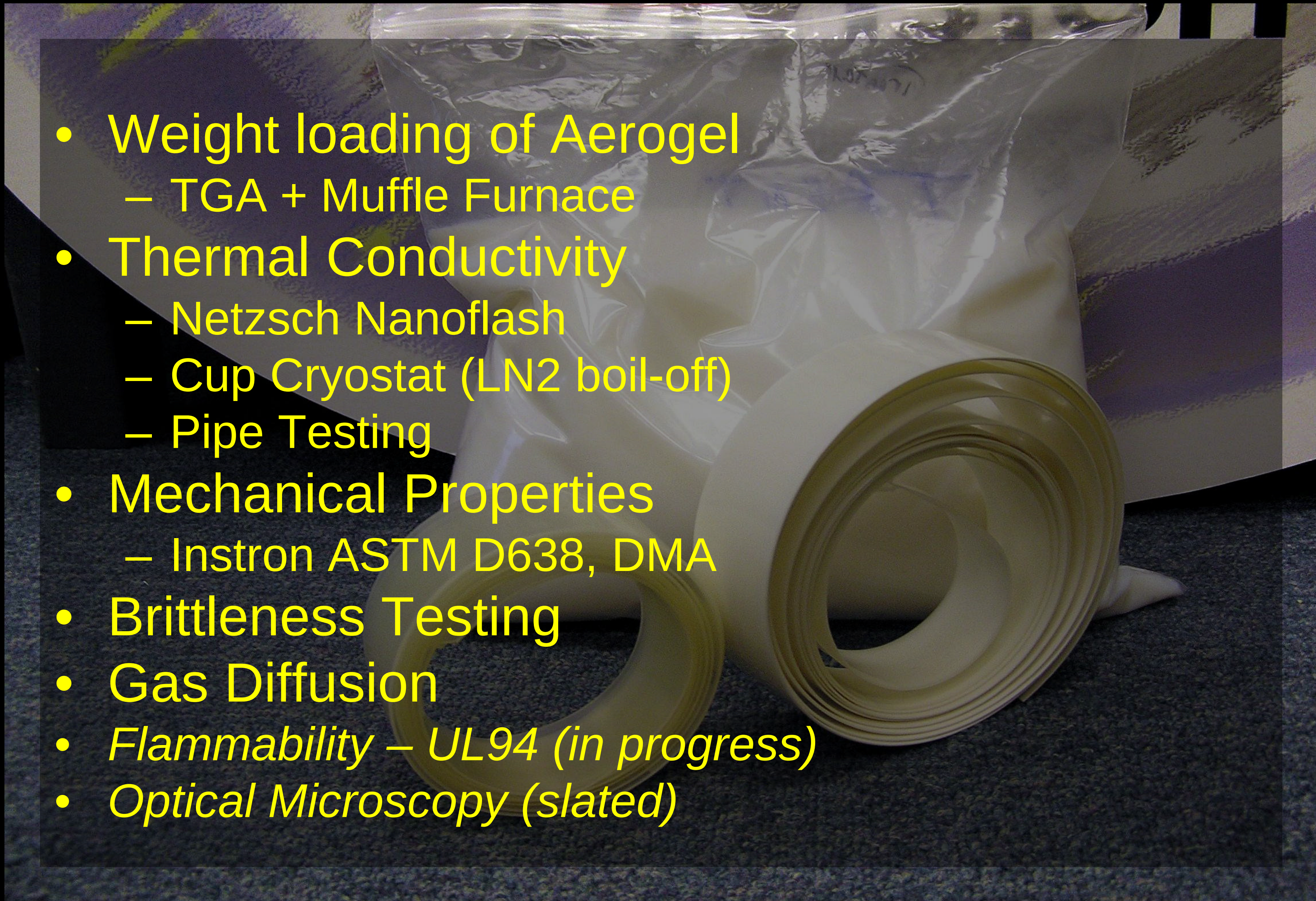


AeroDisk Coaster (3” Diameter, 0.25” thick)



AeroCup (3” Diameter, 0.25” thick)

Characterization



- Weight loading of Aerogel
  - TGA + Muffle Furnace
- Thermal Conductivity
  - Netzsch Nanoflash
  - Cup Cryostat (LN2 boil-off)
  - Pipe Testing
- Mechanical Properties
  - Instron ASTM D638, DMA
- Brittleness Testing
- Gas Diffusion
- *Flammability – UL94 (in progress)*
- *Optical Microscopy (slated)*

Aerogel Loading Data

1 mm Beads with Mixing Screws

Material	Sample Identity	Aerogel Wt % Added	Weight % Achieved	
			TGA (N2)	Muffle Furnace
Nanogel	Cabot Nanogel	100	85.00	98.75
MXD6	L1 MXD6 5% Aero to L2	5	22.51	1.06
	L2 MXD6 Neat	0	18.04	0.09
	T1 MXD6 5% Aero to T2	5	19.53	2.63
	T2 MXD6 Neat	0	15.30	0.05
	T3 MXD6 15% Aero to T2	15		9.65
			TGA (Air)	
PA66	LR27A (PA66 Neat)	0	0.65	0.05
	LR27B (PA66 5% AG)	5	5.47	3.95
	P6N2106 (PA66 Neat)	0	9.38	0.04
	P61A10196 (PA66 1% AG)	1	10.38	
	P65A2226 (PA66 5% AG)	5	14.05	4.51
Versify	Versify 2300 Neat	0	-0.04	0.00
	Versify 2300 5% Aerogel	5	4.71	3.66
	Versify 2300 10% Aerogel	10	7.27	10.00
	Versify 2300 15% Aerogel	15	7.90	
	LR27C (Versify Neat)	0	3.08	0.05
	LR27D (Versify 5% AG)	5	7.13	5.28
	Versify Pipe Sample Neat	0		0.09
	Verisfy Pipe Sample Aerogel	5.8		5.11

Aerogel Loading Data

with Mixing and Kneading Screws*

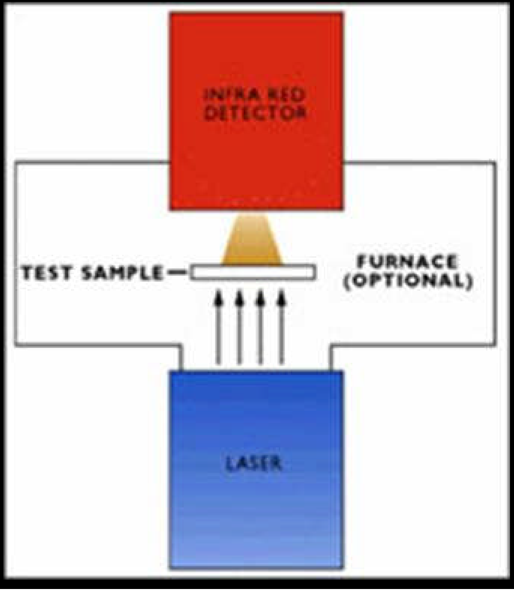
Material	Sample Identity	Aerogel Wt % Added	Weight % Achieved	
			TGA (Air)	Muffle Furnace
Single Extrusions				
PP	102 Disk 6 4-30-8	15	5.83*	
	Ball Milled Aerogel 1-29-8	15	5.52*	
	Granules 6-13-8	15	10.21	
	15 APP 13 3-13-8	15	5.15*	
Versify	Neat	0	0.00*	0.05*
	Beads 4-24-8	10	7.00*	6.50*
	10 Aero bead disk 10 4-29-8	10	5.50*	
	10 Aero bead disk 7 4-29-8	10	5.47*	
	10 Aero bead disk 4 4-29-8	10	5.52*	
	201 4-25-8	10	2.00*	2.05*
	201 Disk 6 5-1-8	10	1.67*	
	102 4-18-8	15		7.91*
	102 Disk 2 4-18-8	15	3.76*	
	102 Disk 6 4-18-8	15	5.83*	
	102 Tape 4-25-8	10	6.67*	
	Granules 6-13-8	15	7.17	
Double Extrusion with Inection Molding				
PP	PP Neat Disk 11 6-26-8	0	0.83	
	D15% G Pellets 6-13-8	30	22.30	
	D15% G Disk 6 6-17-8	30	22.22	
	D15% G Disk 5 6-13-8	30	22.10	
	D15% 102 Disk 6 6-23-8	30	19.01	
	D15% 102 Pellets 6-23-8	30	20.02	

Thermal Conductivity

Netzsch NanoFlash 447

Specifications:

Conforms to ASTM E1461
Measuring thermal diffusivity directly
Measuring specific heat with reference sample
Thermal conductivity =
thermal diffusivity x density x specific heat
Xenon flash lamps with InSb IR Detector
Temperature Range: ambient - 300 C
Thermal diffusivity range: 0.001 - 10 cm^2/s
Accuracy: 5%
Repeatability: 3%



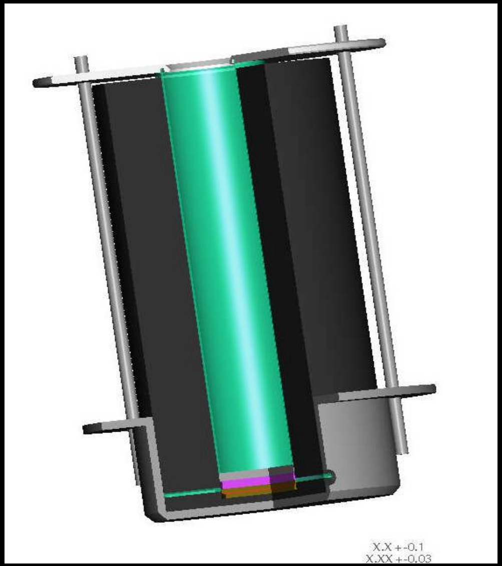
Preferred specimen size: round (25.4 or 12.7 mm in diameter) or square (8 mm side length)

NanoFlash Thermal Conductivity Data

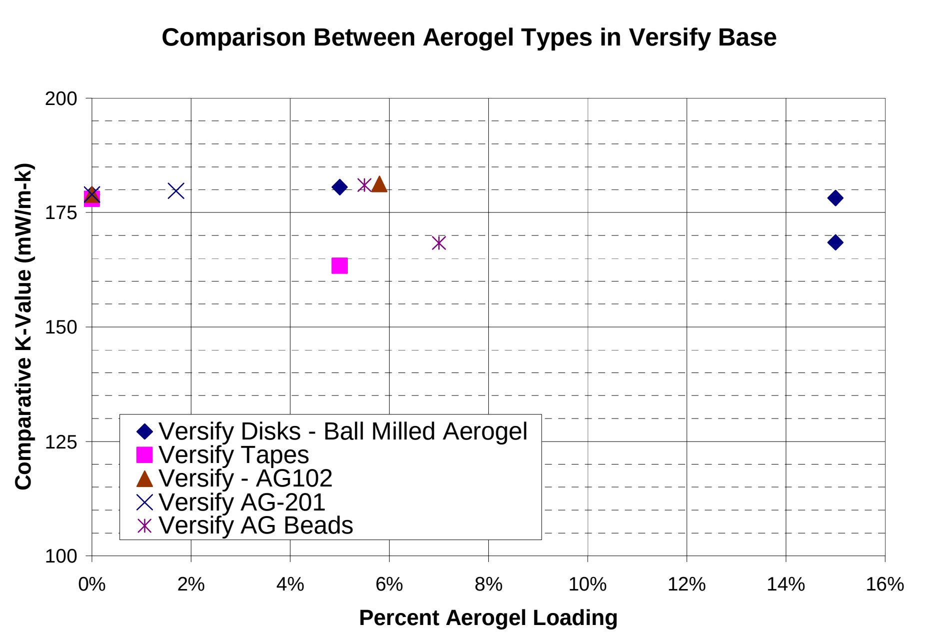
Material	Thermal conductivity (W/mK)	Thermal conductivity reduction from neat
MXD6 neat, sample 1	0.217	
5% aerogel-MXD6, sample 1	0.115	47%
MXD6 neat, sample 2	0.294	
5% aerogel-MXD6, sample 2	0.175	40%
ULTEM neat	0.335	
5% aerogel-ULTEM	0.182	46%
PA66 neat	0.454	
5% aerogel-PA66	0.320	30%
PA66 neat	0.292	
5% aerogel-PA66	0.216	26%

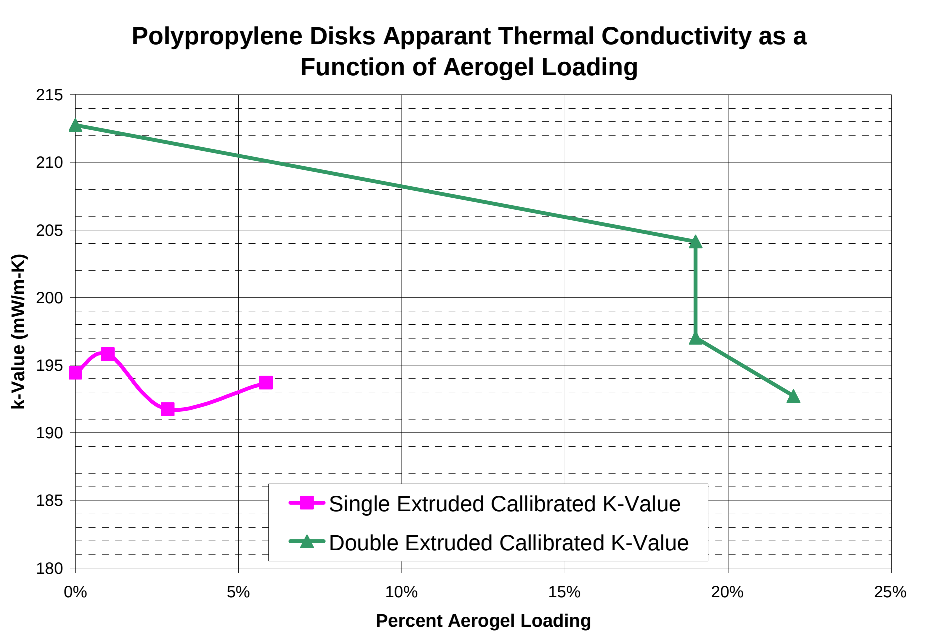
Cup Cryostat Testing

Apparent Thermal Conductivity (k-value)

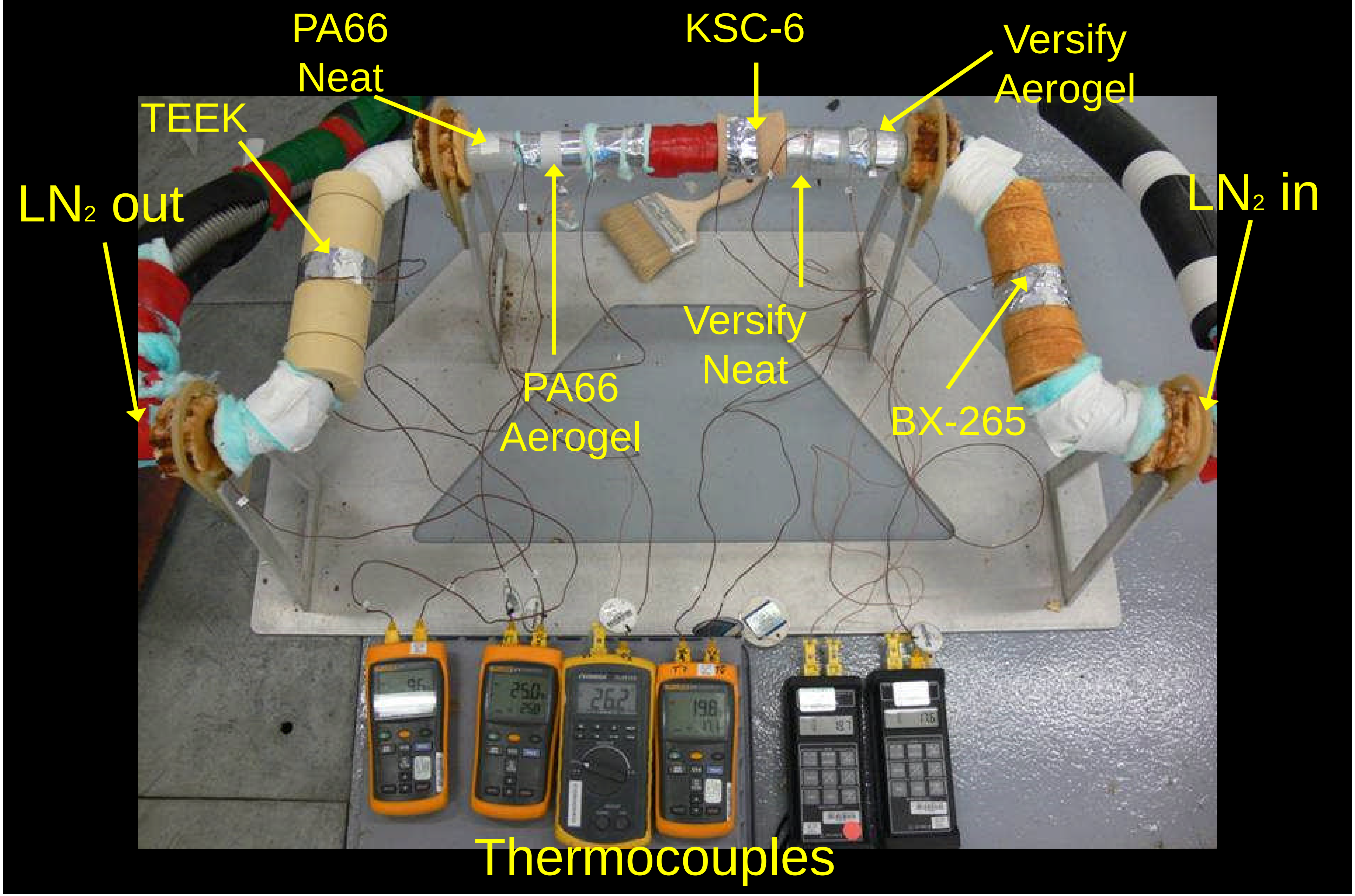


- Testing done on disks
  - 3 inch diameter
  - 0.25 inch thickness
- Cold Boundary = 78 K
  - Liquid Nitrogen maintained
- Warm Boundary = 293 K
  - Heater maintained

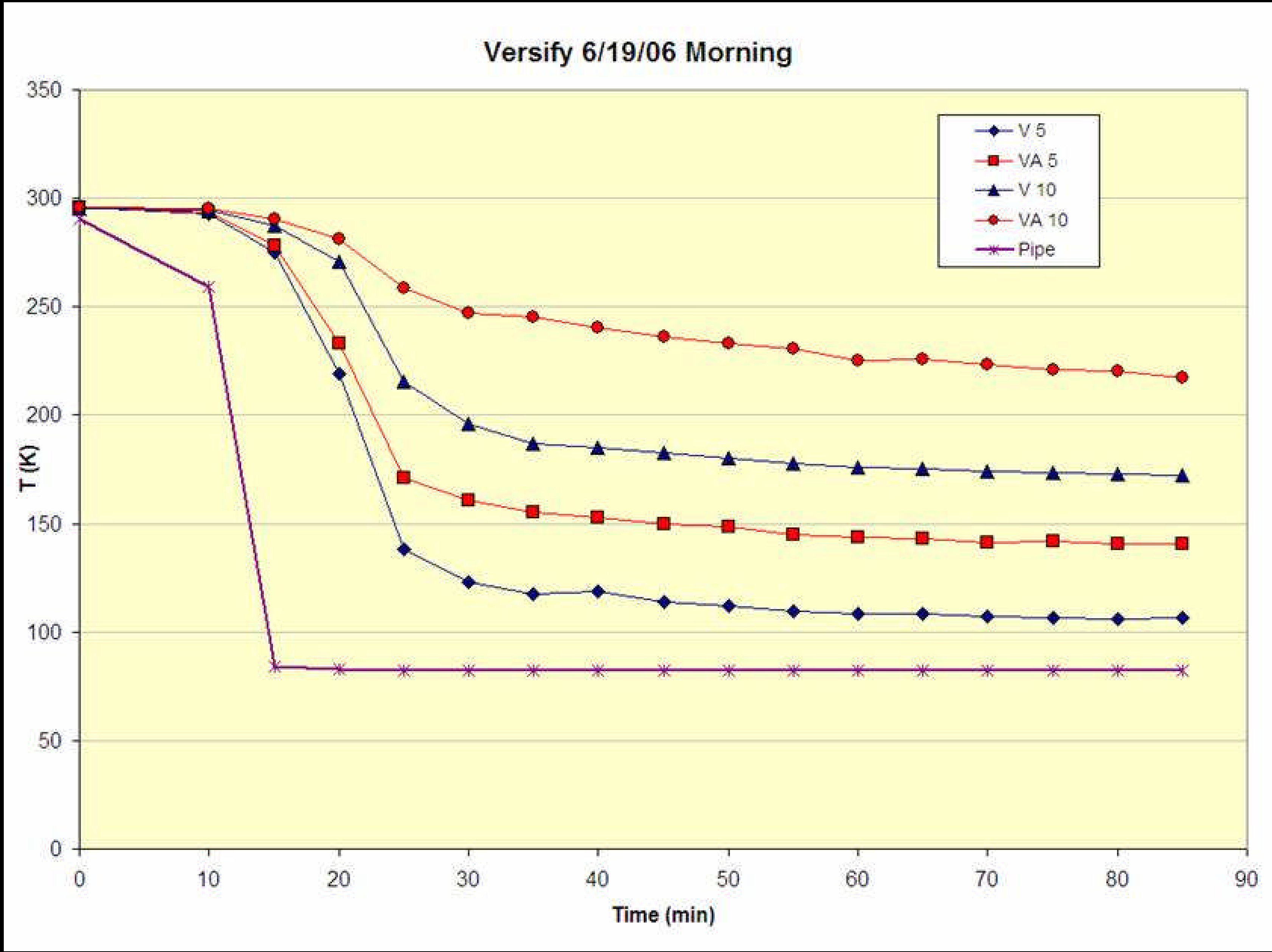




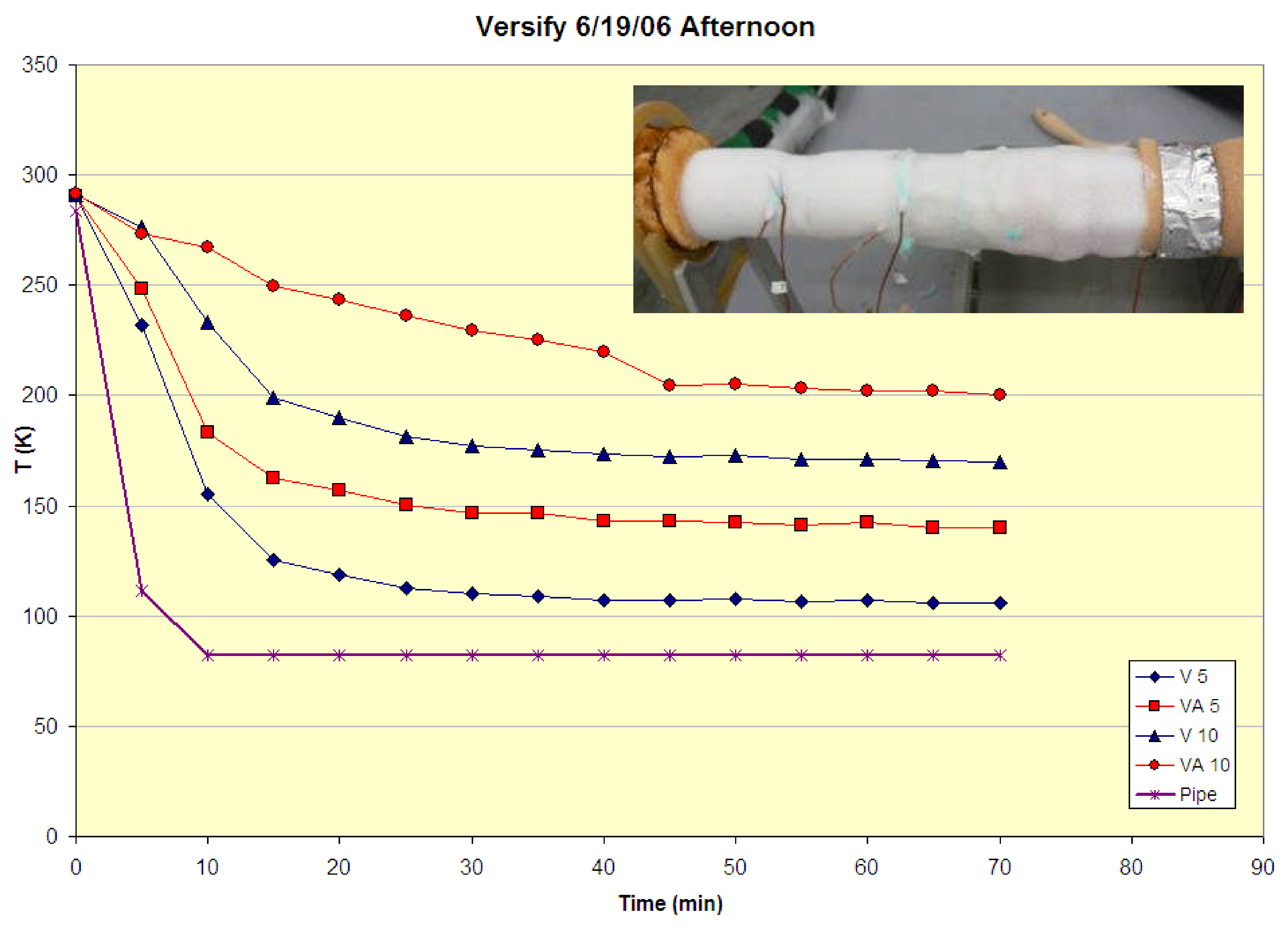
Cryogenic Pipe Test Apparatus



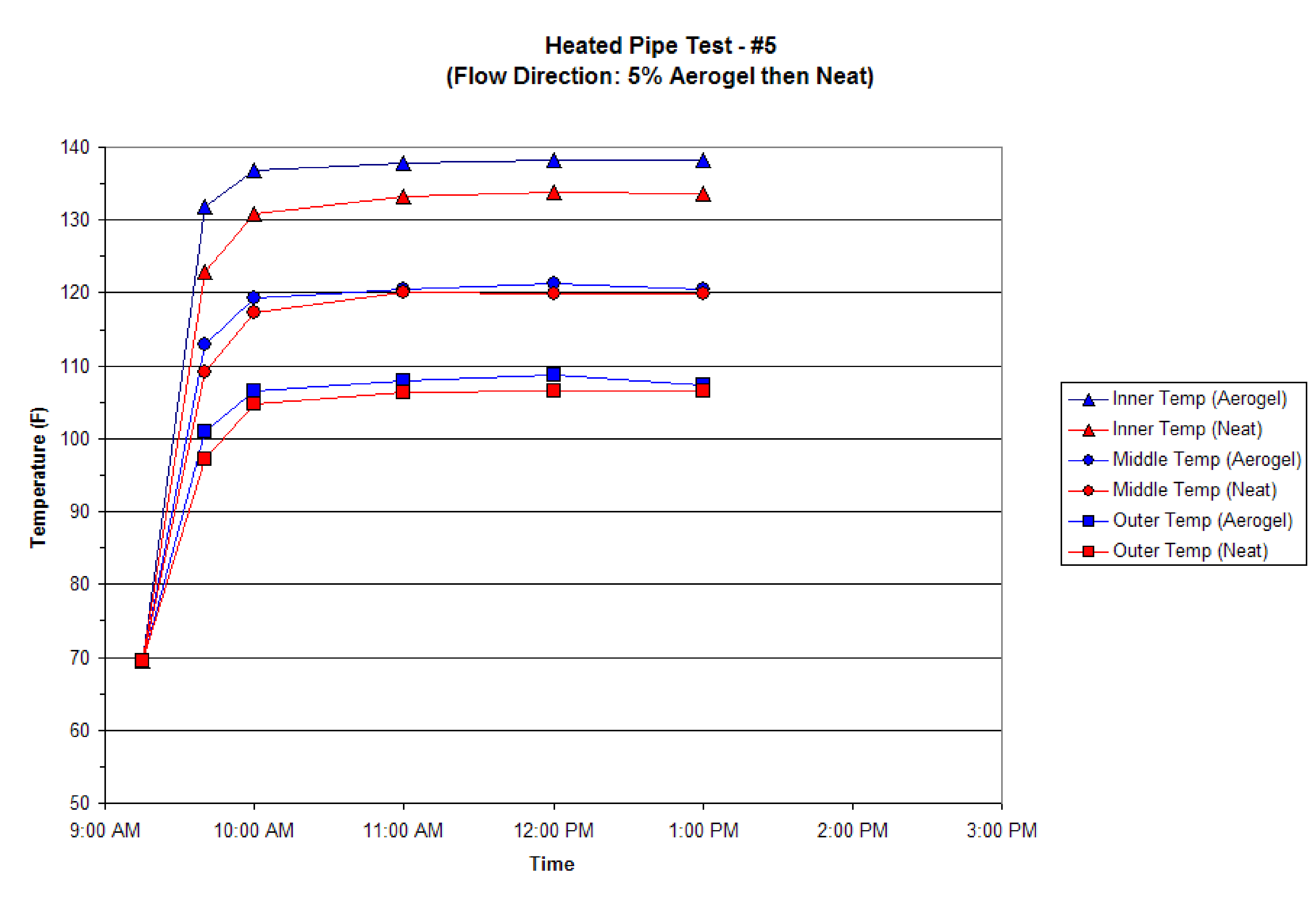
Cryogenic Pipe Test Demo– Versify Data



Cryogenic Pipe Test Demo – Versify Data



Heated Flow Pipe Test Demo

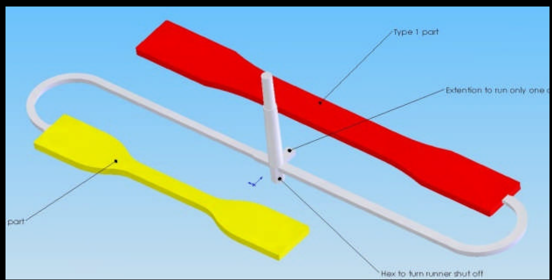


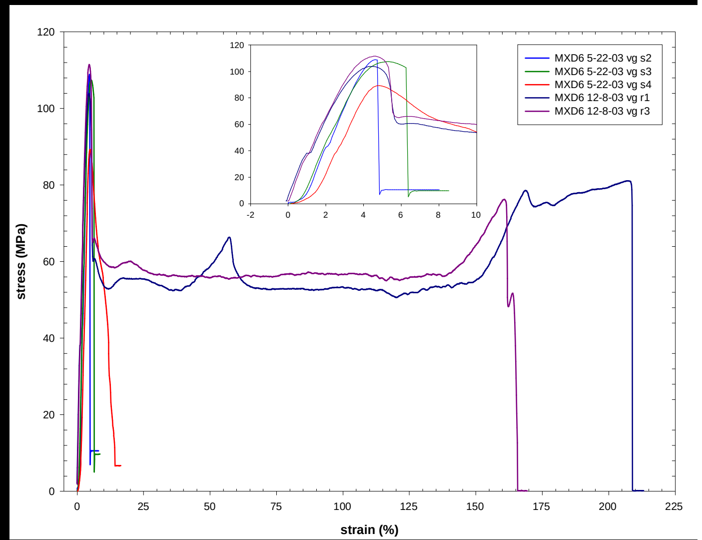
Thermal Conductivity Test Results

- From the Netzsch Nanoflash data, materials show 40-60% improvement in thermal conductivity with minimum loading
- From the pipe test data using tape fabrication, materials show improved insulating properties at cryogenic temperatures
- From extrusion and injection molding, materials show lowered thermal conductivity with the addition of Aerogel

Mechanical Testing

Tensile Testing: ASTM D638 Data

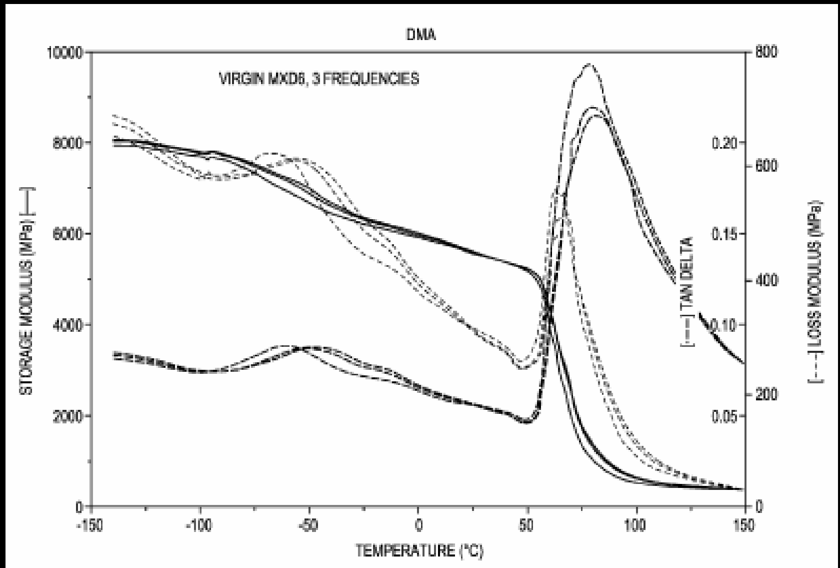


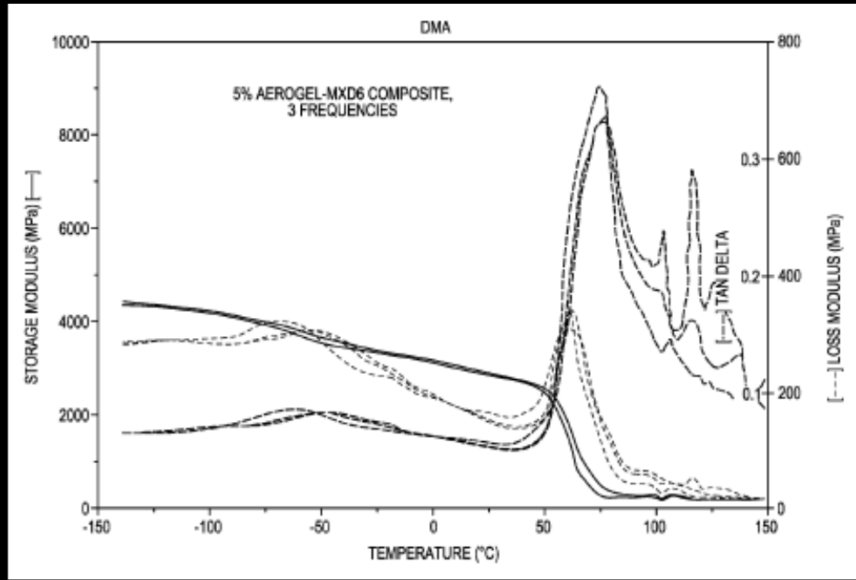


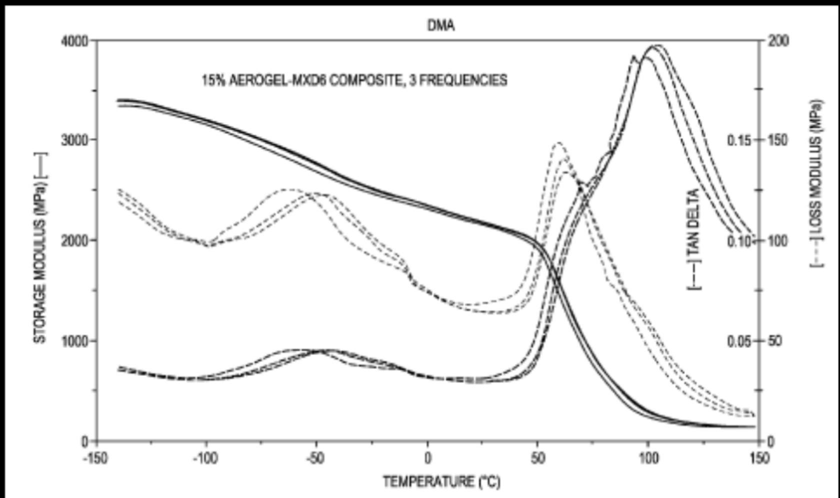
Material	yield stress (psi)	yield strain (%)	number of samples
MXD6 neat	97.0 ± 11.3	4.1%	6
5% aerogel-MXD6	99.3 ± 8.2	4.1%	3

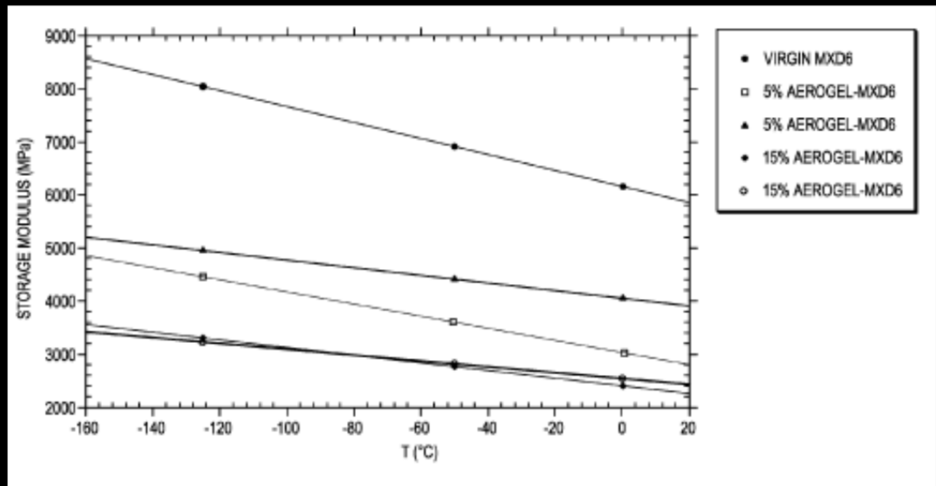
Mechanical Testing

DMA Data









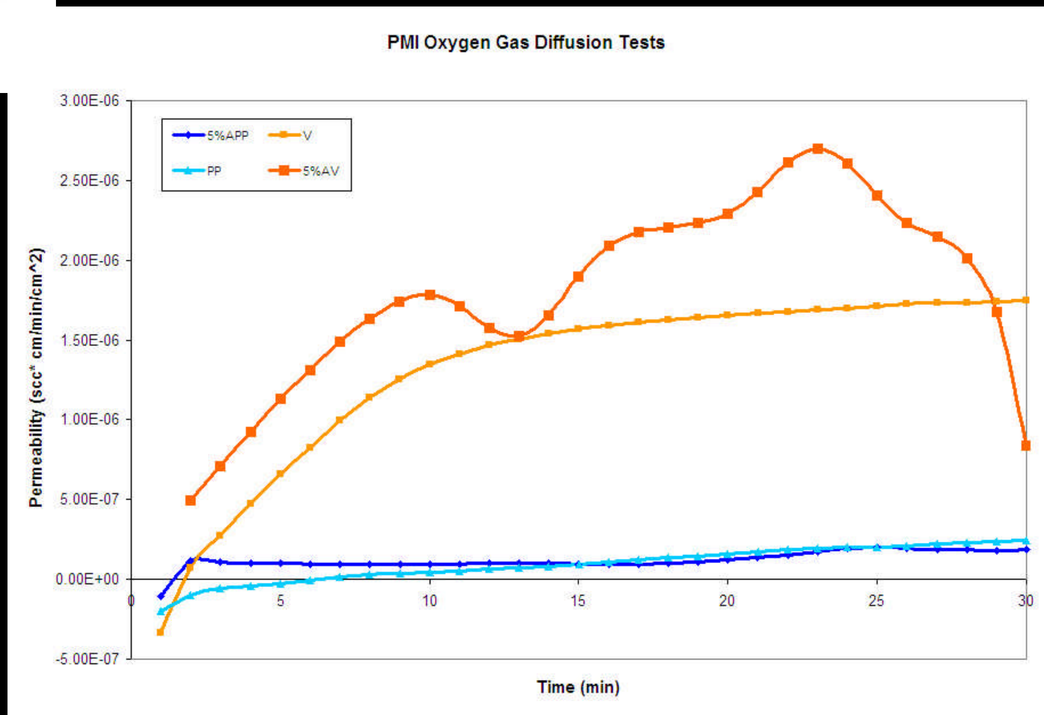
Gas Permeability Testing

ASTM

MOCON Oxtran 2/10

O_2 Range: 0.1 - 144,000 cc/m – day

Data provided by Porous Materials Inc.

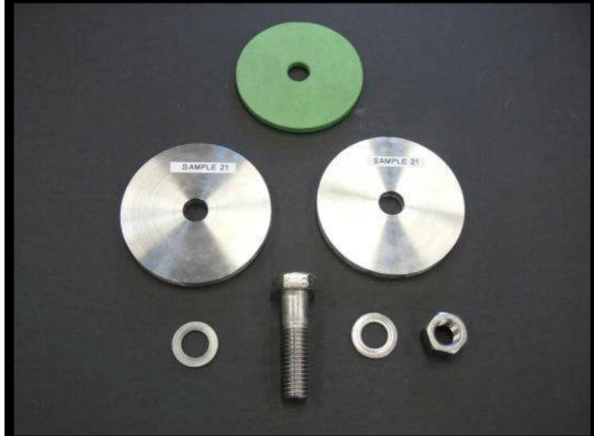


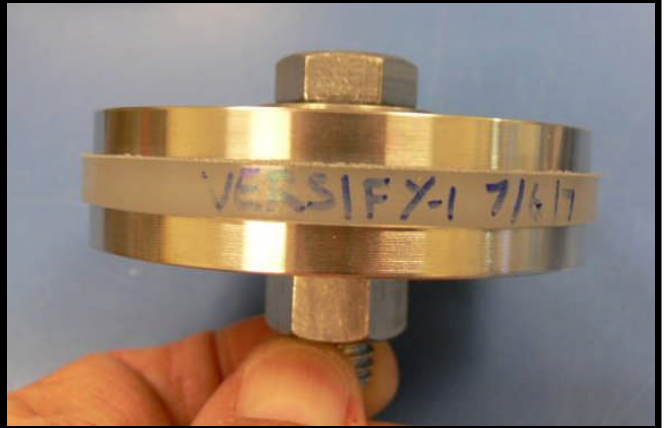
Versify-5% Aerogel run twice

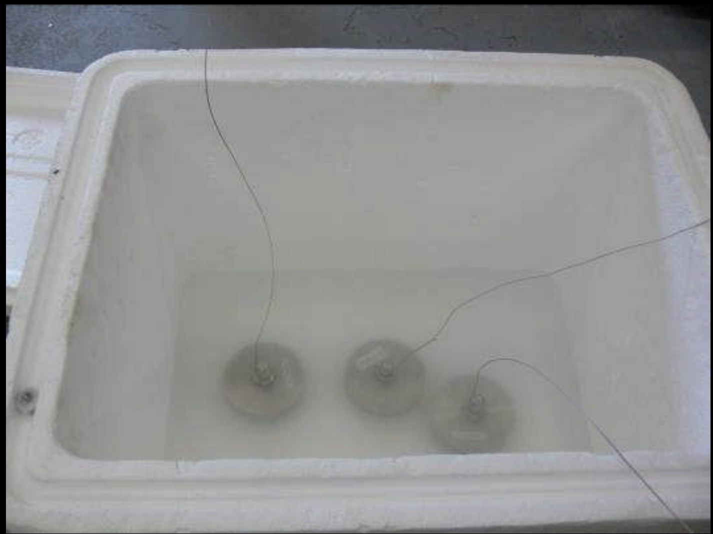
Data within machine error

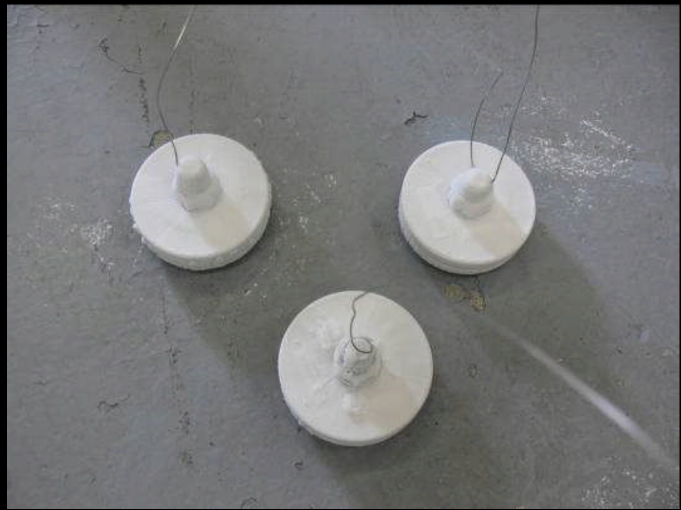
No O2 gas permeability

Mechanical Compression Testing

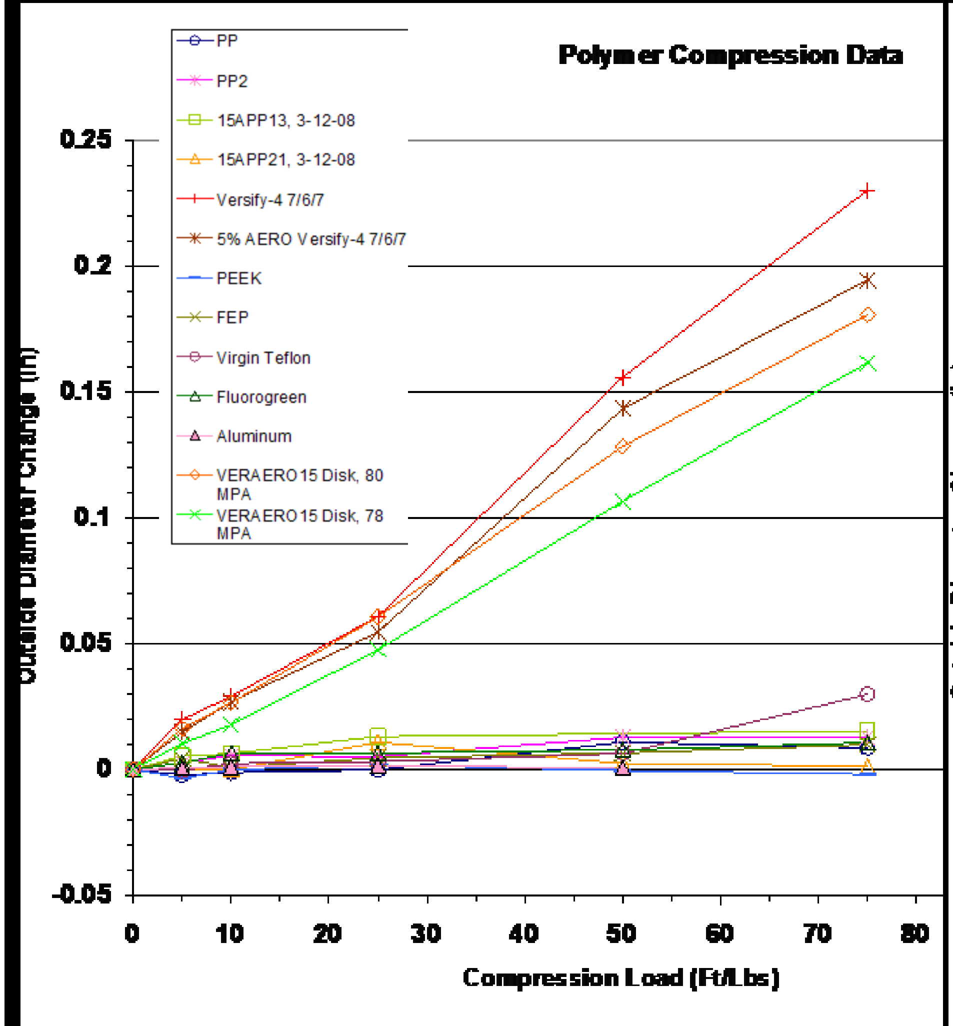


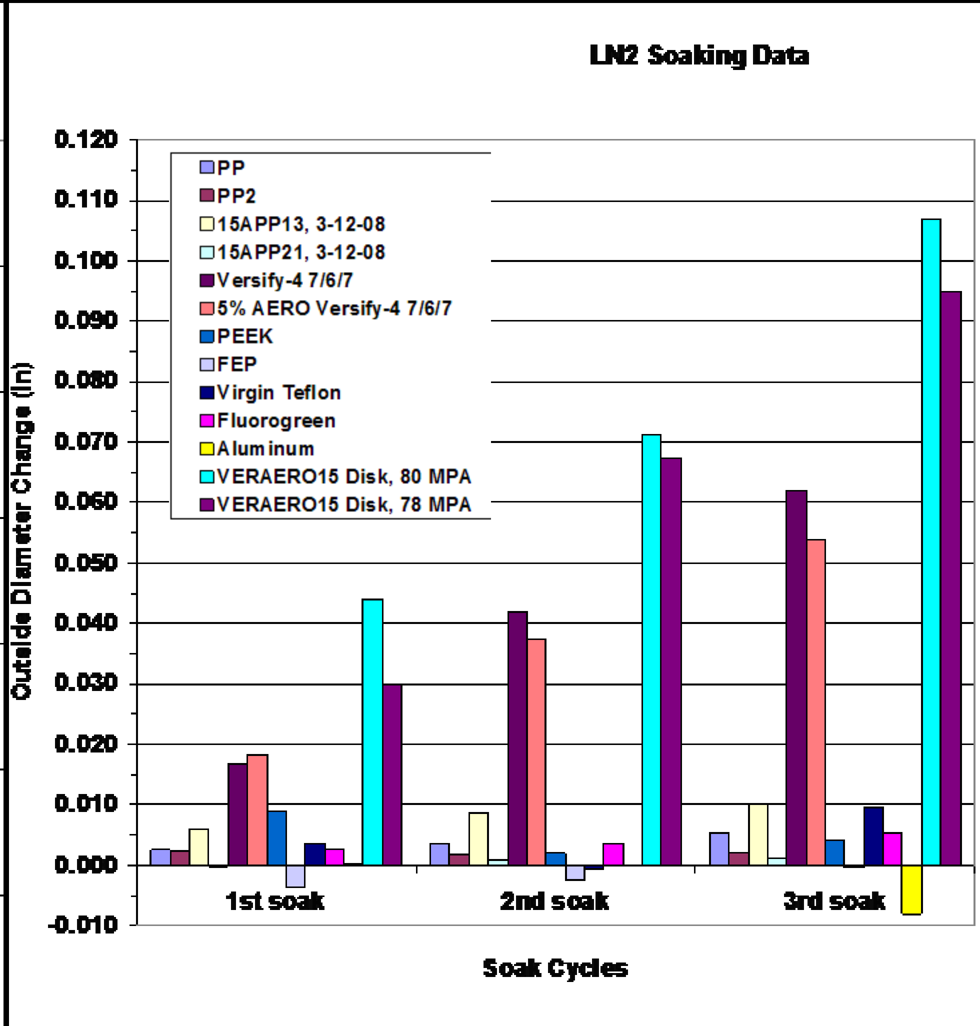






Valve Seal Compression Testing





SUMMARY

- Adding of aerogel to polymer resins decrease thermal conductivity or overall rates in heat transfer
- No significant reduction in mechanical properties such as tensile strength was observed in data collected
- Enable wider use of thermoplastics at cryogenic or lower temperatures –for certain matrices test results indicate the nanocomposite to be more elastic and less brittle than base polymer at low temperatures
- Industry-standard polymer processing methods are used; process is suitable for molded and extruded product forms, film and fiber products