Polymeric Materials for Aerospace Power and Propulsion-NASA Glenn Overview

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Use of lightweight materials in aerospace power and propulsion components can lead to significant reductions in vehicle weight and improvements in performance and efficiency. Polymeric materials are well suited for many of these applications, but improvements in processability, durability and performance are required for their successful use in these components. Polymers Research at NASA Glenn is focused on utilizing a combination of traditional polymer science and engineering approaches and nanotechnology to develop new materials with enhanced processability, performance and durability. An overview of these efforts will be presented.

Polymeric Materials for Aerospace Power and Propulsion – NASA Glenn Overview

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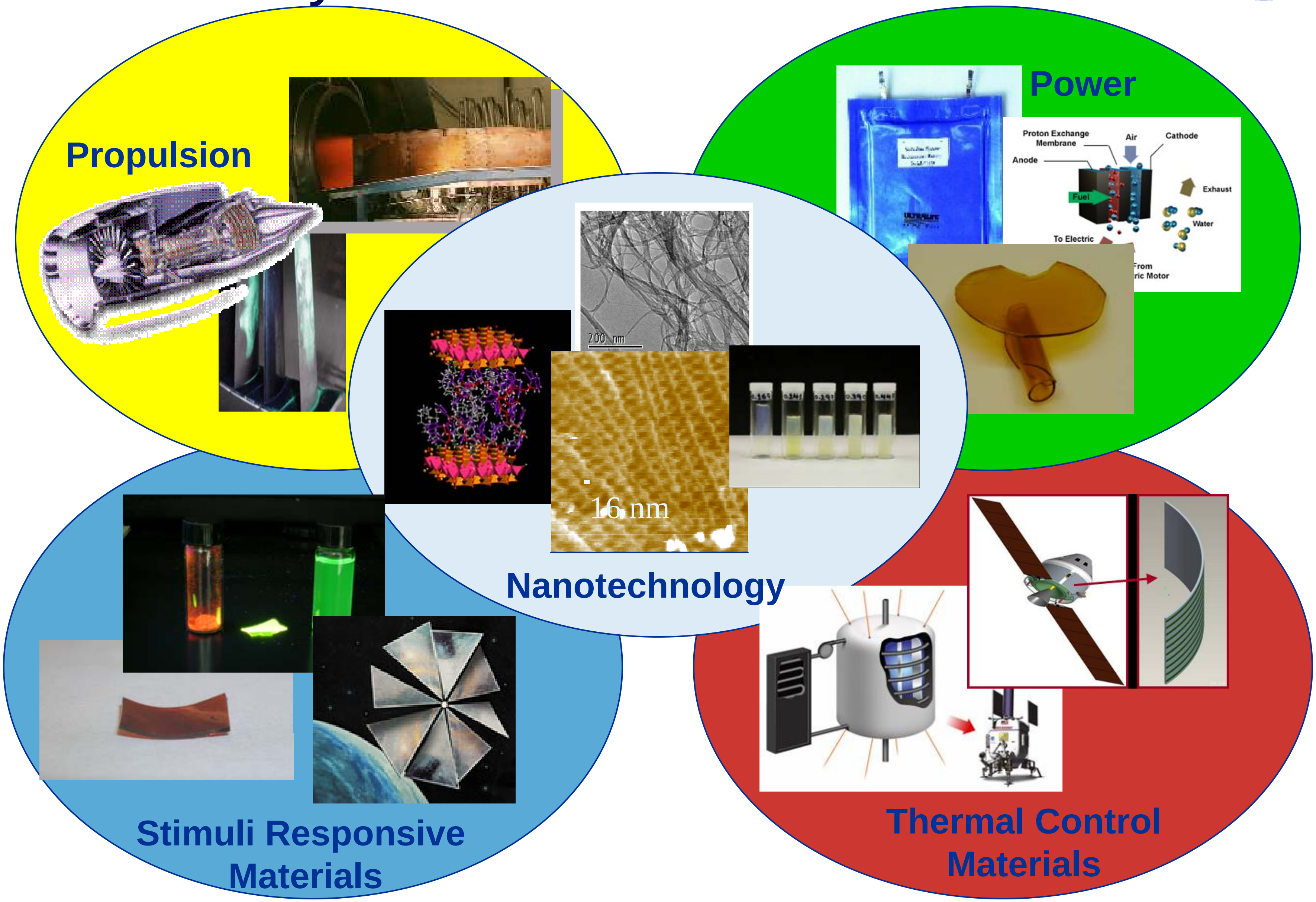
Polymers Branch R&D Efforts



GRC Polymeric Materials Research Efforts in Aeronautics

- Subsonic Rotary Wing Aircraft
  - Multifunctional acoustic insulation – gearbox noise
- Subsonic Fixed Wing Aircraft
  - Multifunctional materials for acoustic lines for aircraft engine
  - Adaptive materials
- Supersonics
  - RTM processable 600°F resins for bypass ducts and containment systems, includes nanocomposites
  - High temperature containment (500-600°F)
- Hypersonics
  - Thermal protection systems
  - High temperature ballutes – Mars landing
- Aging Aircraft
  - Effects of aging on ballistic impact behavior of composites

RTM/RFI Processable Polymers for Propulsion Components

Objective:

Develop low melt viscosity polymers for RTM, VARTM or RFI processing of high temperature propulsion components

- Melt viscosities below 20Poise
- Tg and TOS suitable for use from 500-600°F

Approach:

- Modify oligomer chemistry to reduce viscosity with minimal effect on Tg and TOS
  - Molecular morphology – branching, twists, asymmetry
  - Formulated molecular weight
  - Endcap chemistry
- Investigate use of nanoscale filers to enhance TOS and properties

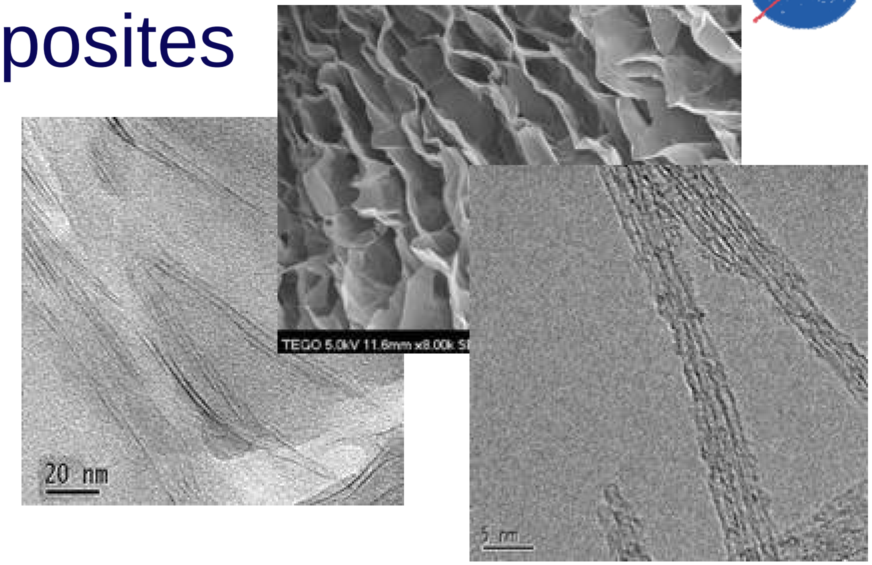
Partners:

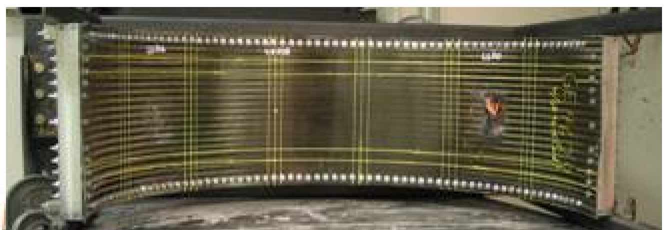
Boeing, Clark Atlanta U, M&P Technologies

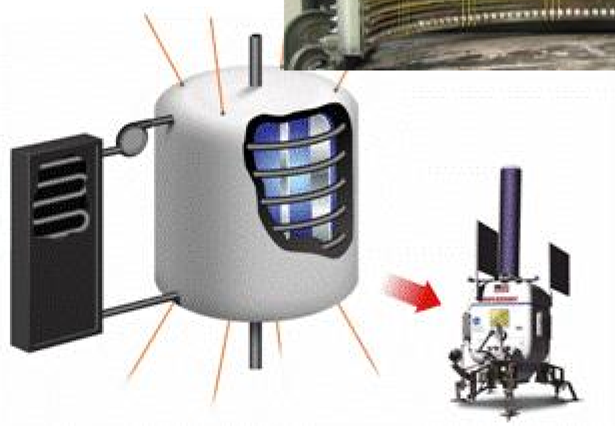
RFI Processed HFPE Panel

RTM Processed PR-520 LH2 Duct

Nanocomposites



- Investigating effects of a variety of nanoscale fillers on properties of polymers
  - Organically modified clays
  - Functionalized graphene sheets (FGS aka TEGO)
  - 



- Potential applications:
  - Cryotanks – *reduced permeability, enhanced microcrack resistance*
  - Fan containment – *improved toughness*
  - High temperature engine structures – *improved TOS, mechanical properties*

Lebron-Colon, Miller, Gintert
Collaborations with: U of Akron, Princeton, Northwestern, MSU, Clark Atlanta U

Multicomponent Nanocomposites

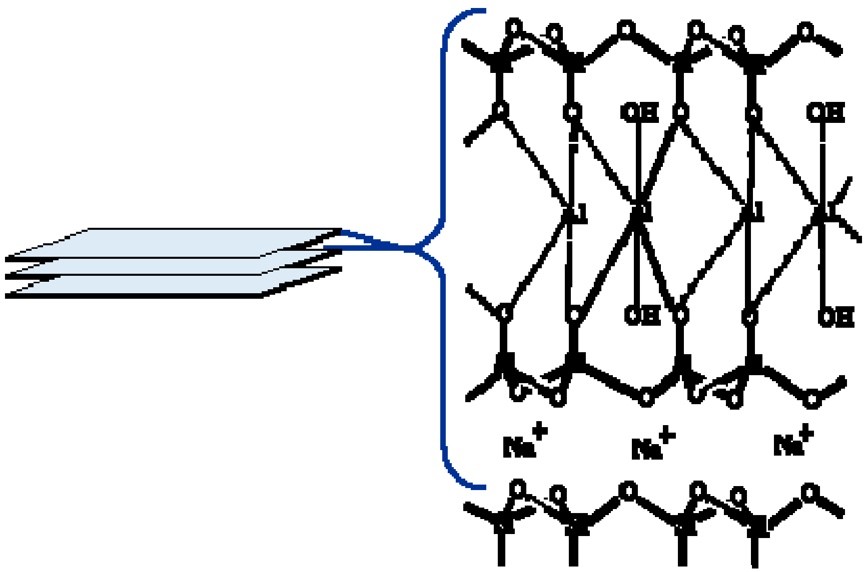
Layered silicate clays:

Platelet morphology provides barrier to oxygen diffusion and oxidative degradation.

- Exfoliated morphology optimizes permeability reduction.

Commonly modified with alkyl ammonium ion

- Degrades at polyimide processing temp.
- Thermally stable modifier is necessary.

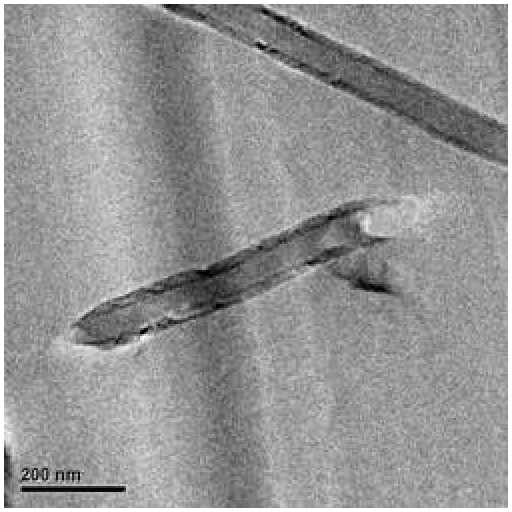


Carbon nanofibers:

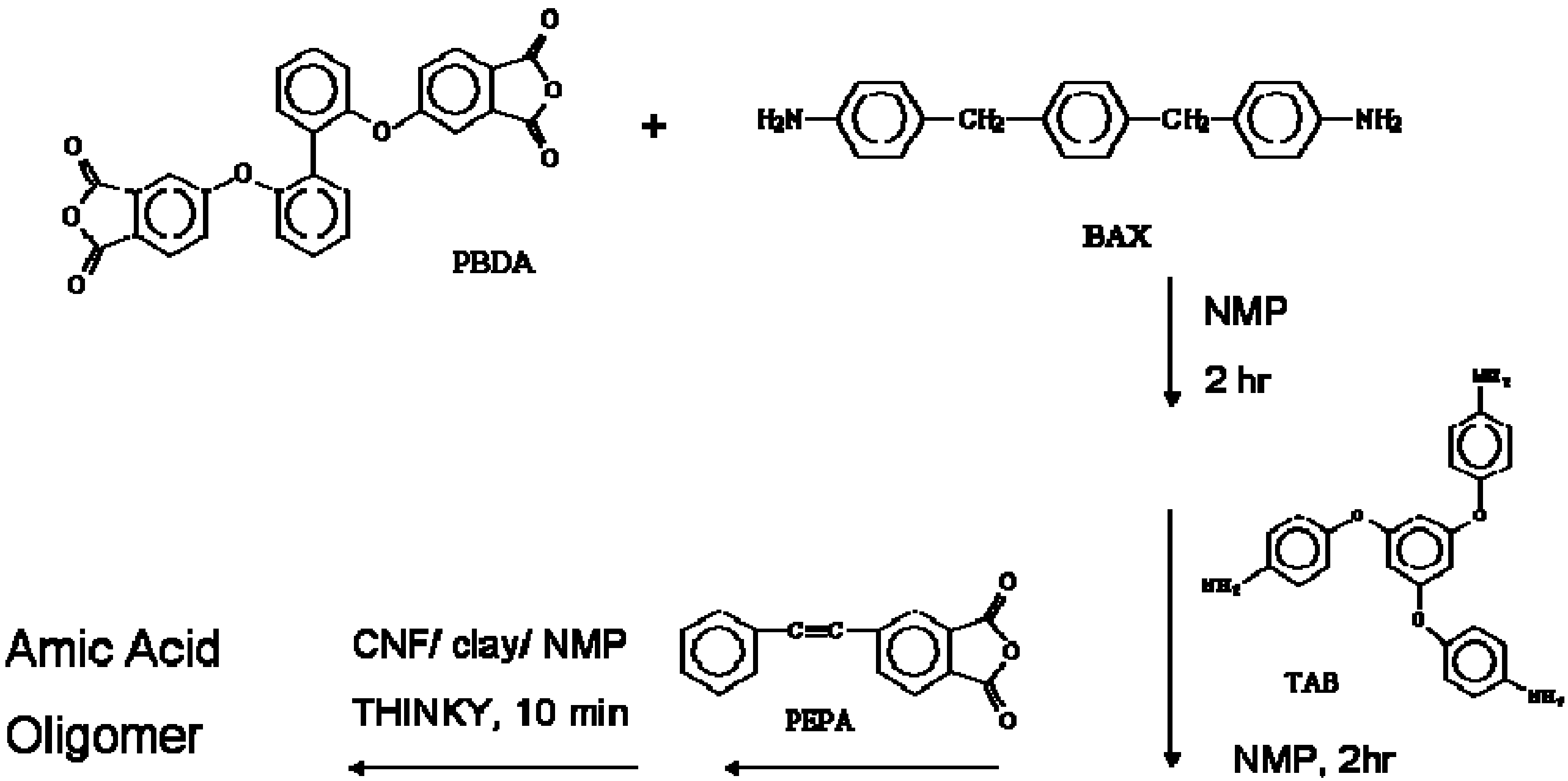
Thermally stable- will not contribute to resin degradation

Imparts mechanical strength and stiffness to the resin.

Thermally conductive



Nanocomposite Synthesis



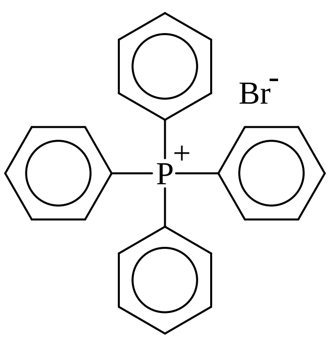
Clay loading: 5 wt%, CNF loading: 0.5 – 1.0 wt%

Use of Synthetic Clay Improves Resin TOS

Melt Viscosities Increase with Clay Addition

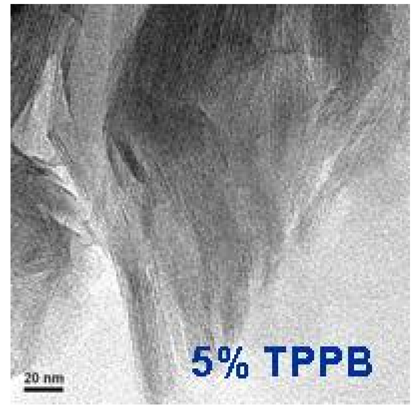
Sample	Minimum Viscosity* [cP]	Temperature (°C)
Neat Resin	~ 10	250
5% TPPB	~ 60	250
5% MSU	~ 40	250

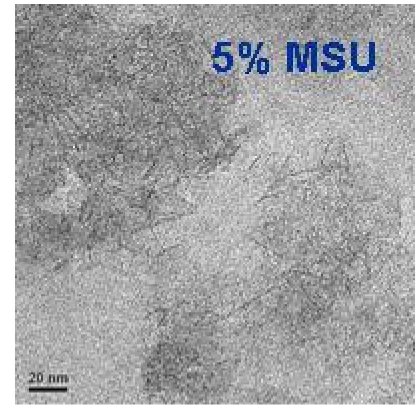
***Measured by Brookfield**



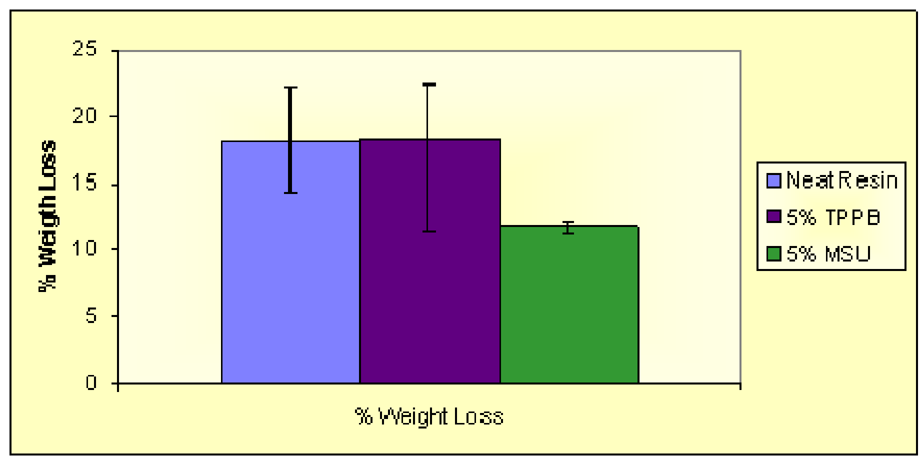
- Examined TPPB modified MMT and synthetic clay
- Used BAX-TAB RTM processable polyimide
- Evaluated TOS, melt viscosity and Tg

Pre-exfoliated Clay Gives Better Dispersion





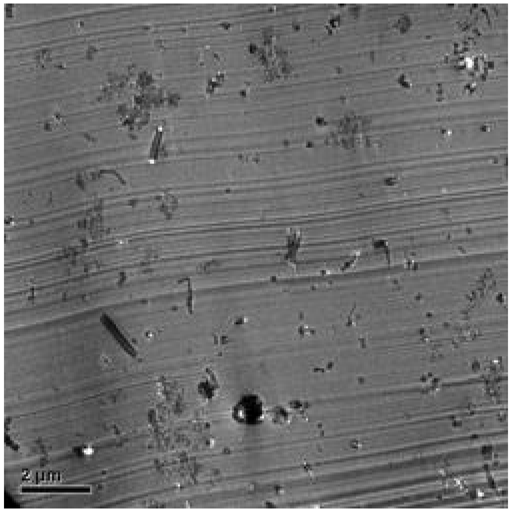
30% Reduction in Weight Loss



Weight Loss after 1000 h at 288°C (550°F)

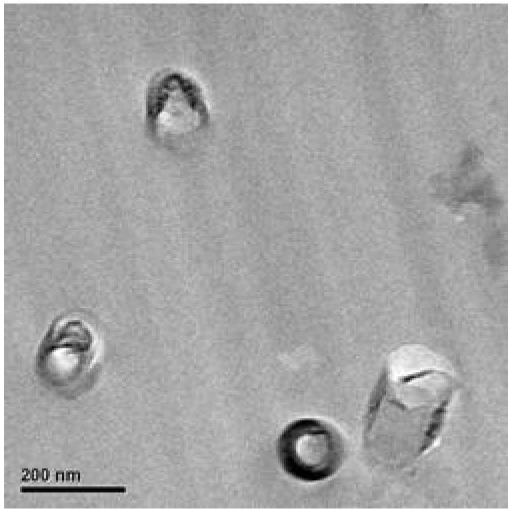
Clay and Nanofiber Dispersion

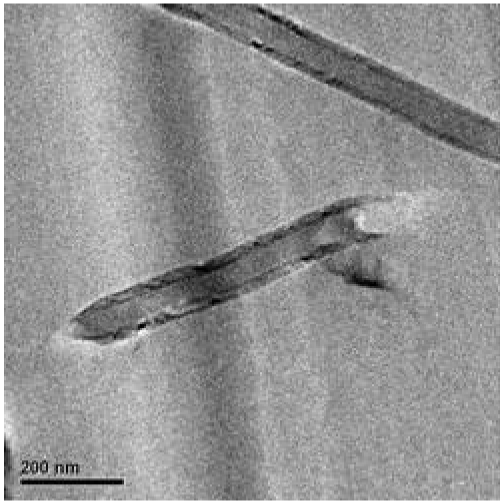
Clay and CNF dispersion characterized by TEM



CNF separation of over 100 nm.

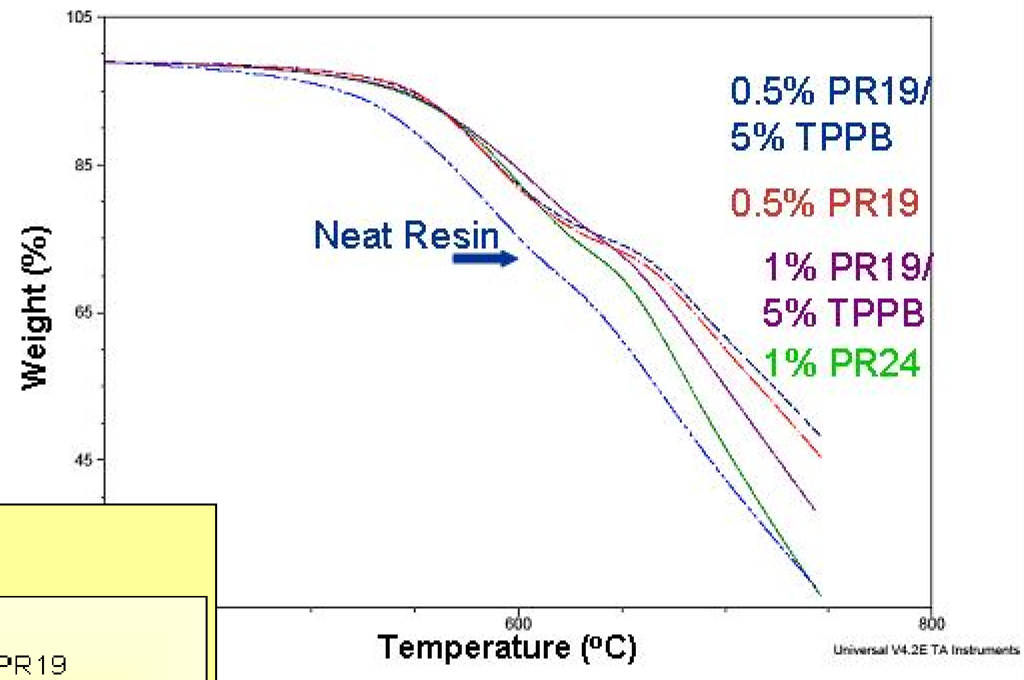
Clay dispersion comparable to clay only nanocomposites

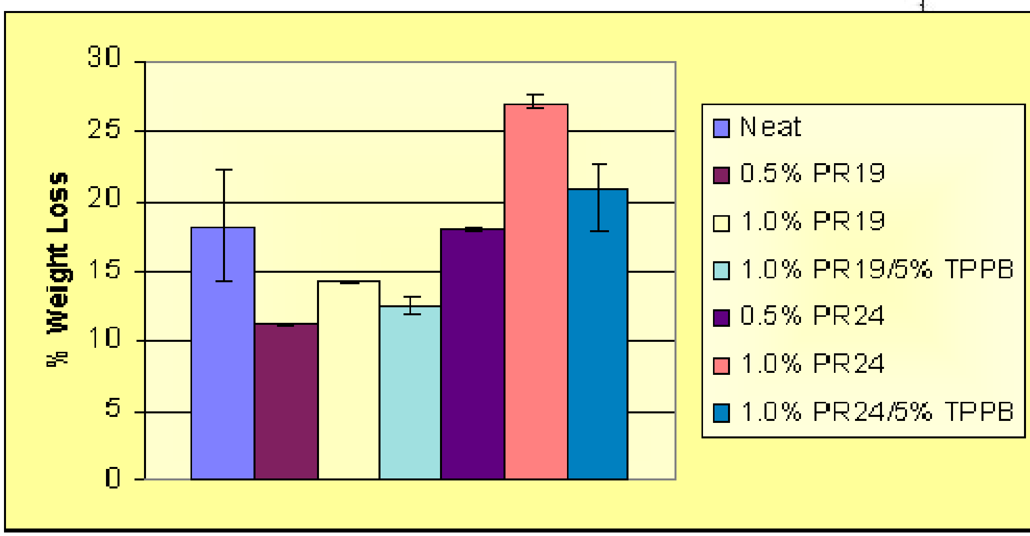




Synergistic Effects of Clay and CNF Addition on Resin TOS Investigated

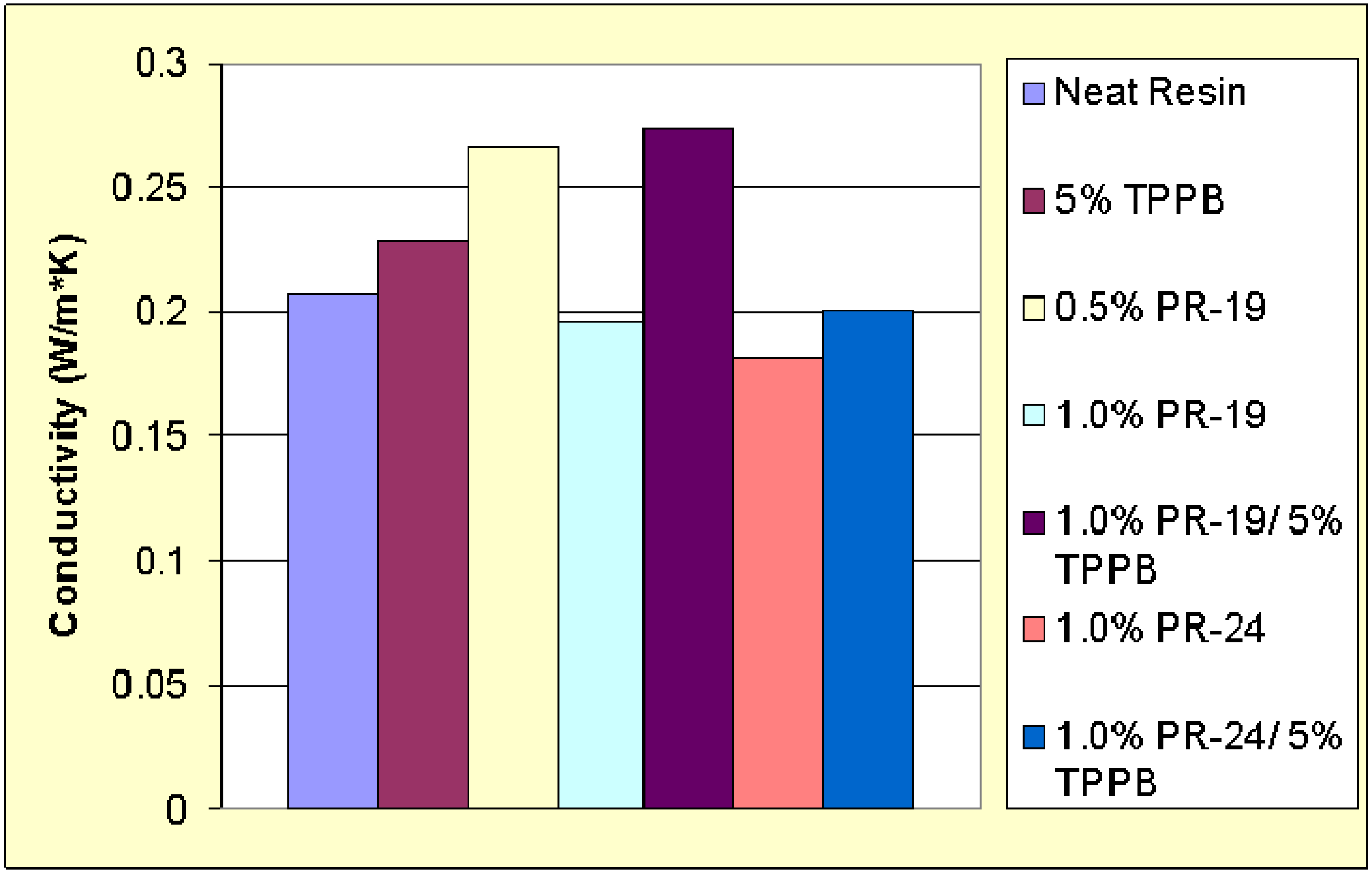
CNF containing nanocomposites increases temperature of 5% and 10% weight loss by 30°C





Nanocomposites containing PR-19 reduce polyimide weight loss on aging by up to 38%

Thermal Conductivity of CNF Nanocomposites



Increased conductivity observed in PR-19 and PR-19/TPPB nanocomposites

Effect of Nanoscale Additive on Melt Behavior

Sample	Minimum Viscosity [P]	Temp. (°C)
Neat Resin	3.5	250
0.5% PR-19	0.5	250
1% PR-19	95	250
1% PR-19/ 5% TPPB	28	250
0.5% PR-24	10	280
1% PR-24	--	--
1% PR-24/ 5% TPPB	0.78	250
5% TPPB	.04	165

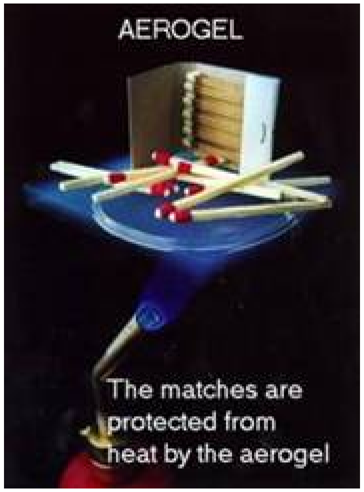
Measured by Parallel Plate Rheology

Dynamic Mechanical Analysis

Sample	Storage Modulus (MPa), 100°C	T_g (°C)
Neat Resin	1558	328
5% TPPB	1558	318
0.5% PR-19	1622	316
1% PR-19	2174	318
1% PR-19/ 5% TPPB	2351	318
0.5% PR-24	1674	323
1% PR-24	1829	315
1% PR-24/ 5% TPPB	2639	313

Increased storage modulus observed with increasing CNF concentration, and on dispersion with clay

Durable Polymer Cross-Linked Aerogels



Conventional Aerogels

- **Low densities**
- **High porosity and surface area**
- **Good electrical and thermal insulators**

Application in NASA missions limited because of poor mechanical and environmental durability

Polymer Cross-linked Aerogels

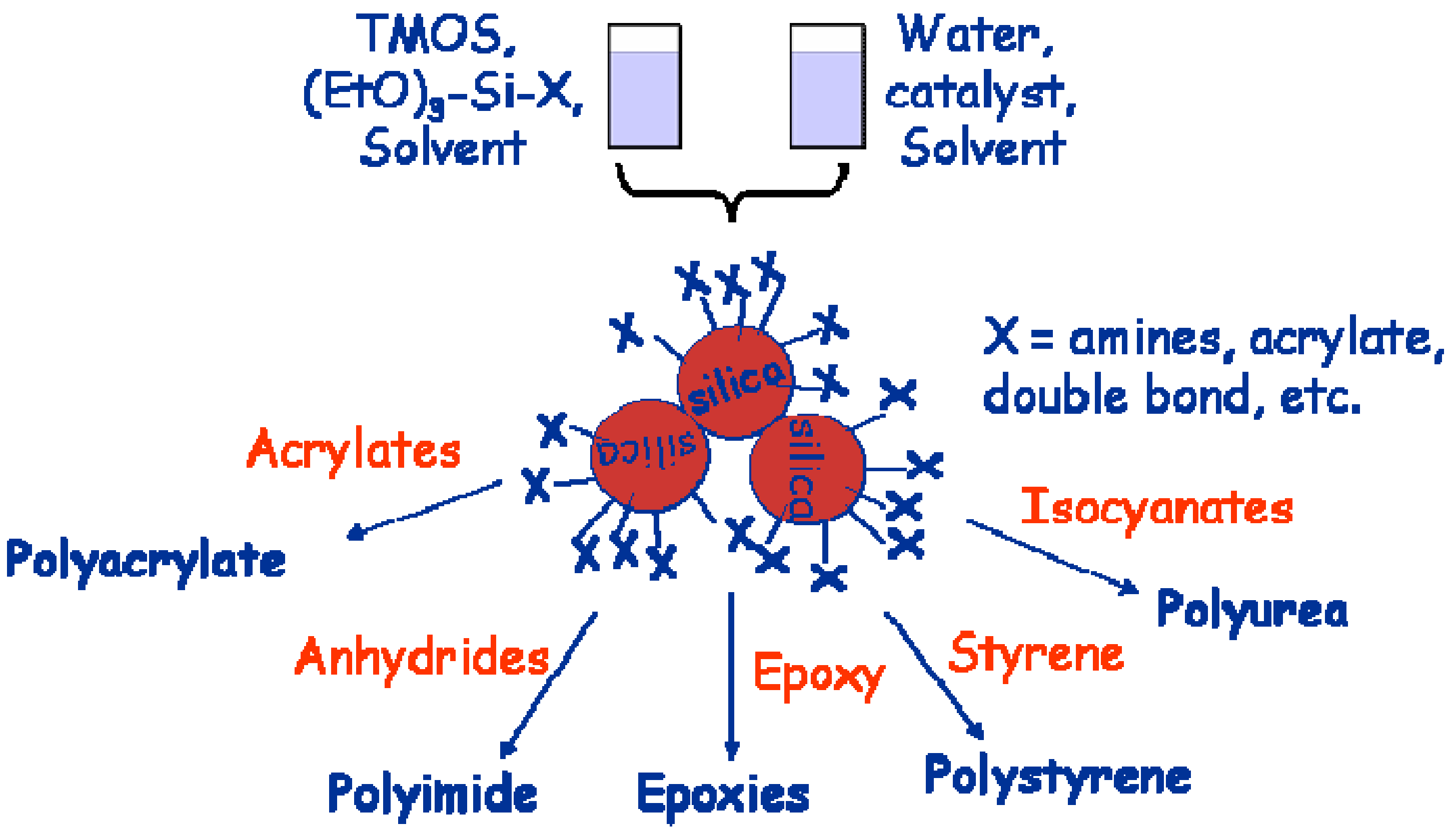
- **Significantly enhanced mechanical properties (up to 300X increase in strength)**
- **Improved durability – some formulations are flexible**
- **Slightly increase in density and thermal conductivity**

New aerogels offer multifunctional solution for many NASA Mission Needs

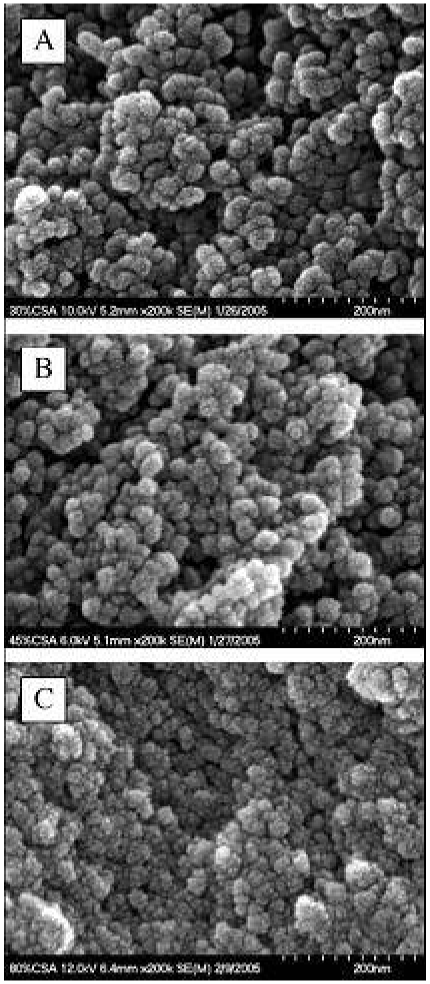
Capadona, Leventis, Meador, Nguyen, Vivod

Collaborations with: Clark Atlanta, U of Akron, Parker Hannifin, ASI, Aspen Aerogels

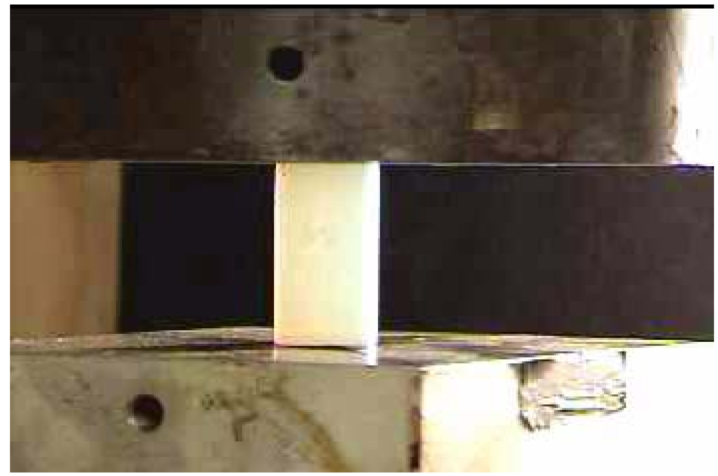
Surface Modification of Silica Particles Opens Doors to Other Polymer Systems



Compression test of crosslinked aerogels



Katti *et al*, *Chemistry of Materials*,
2006, *18*, 285-296



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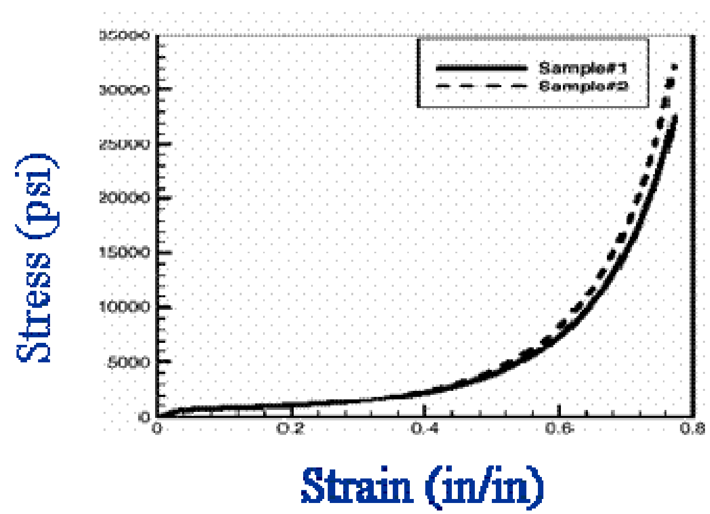
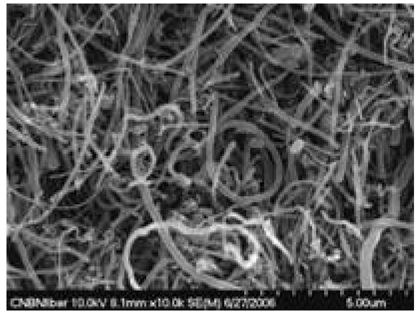


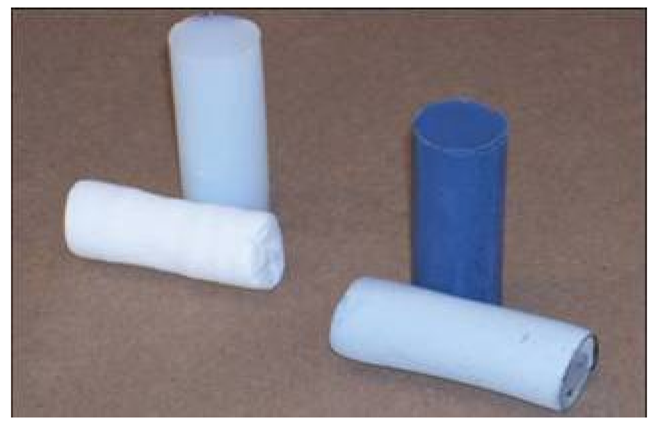
Enhanced Mechanical Properties Through the Addition of Carbon Nanofibers



Pyrograph® Fibers with Proprietary Surface Treatment to Enhance Solvent Compatibility

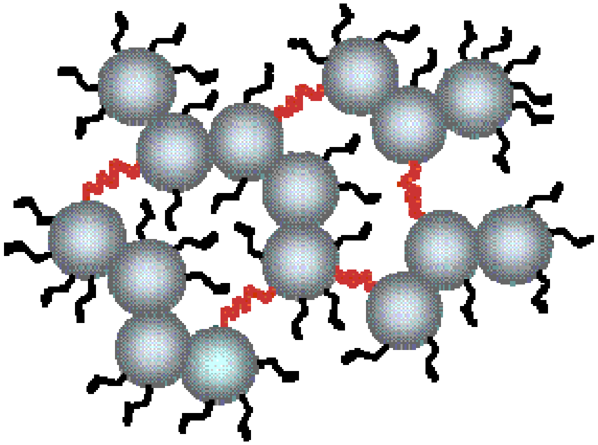
Wet Gels with (right) and wthout (left) Carbon Nanofibers

- **Nanofibers incorporated in the sol – form stable suspensions in acetontrile containin APTES and TMOS**
- **Some fiber dissolution observed upon addition of water**
- **Nanofiber settling observed in gels with higher nanofiber content**



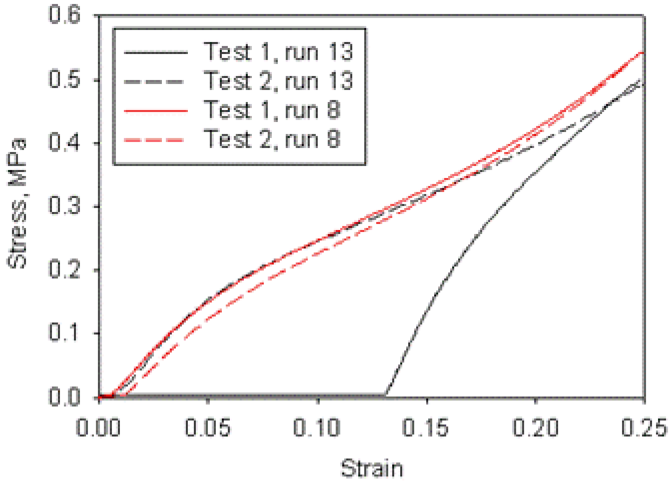
Dry Gels – Those with Nanofibers Have Gray or Blue Appearance

Flex-Link Aerogels Have Improved Flexibility and Durability



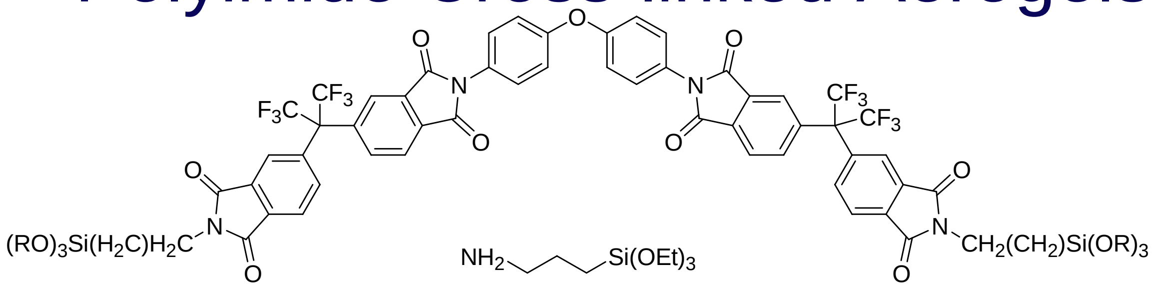
Incorporation of Flexible Linkages in Silica Backbone Enhances Flexibility and Durability

Flex-Link Aerogels Easier to Handle in "Green" State – Better Processability

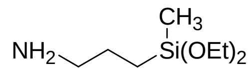


Flex-Link Aerogels Show Better Recovery After Compression

Polyimide Cross-linked Aerogels

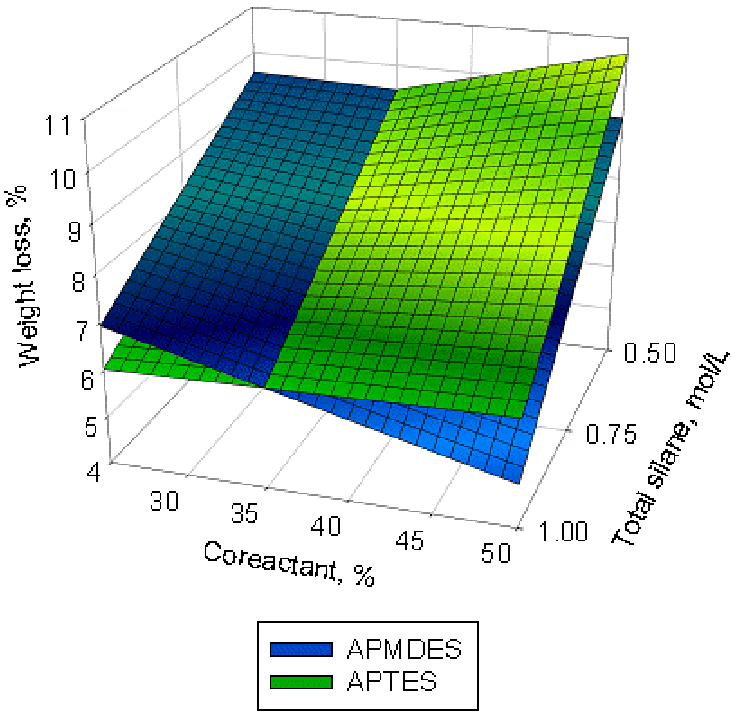


APTES



APDMES

Weight Loss after 1000 h at 200°



Corrected for weight loss due to solvent

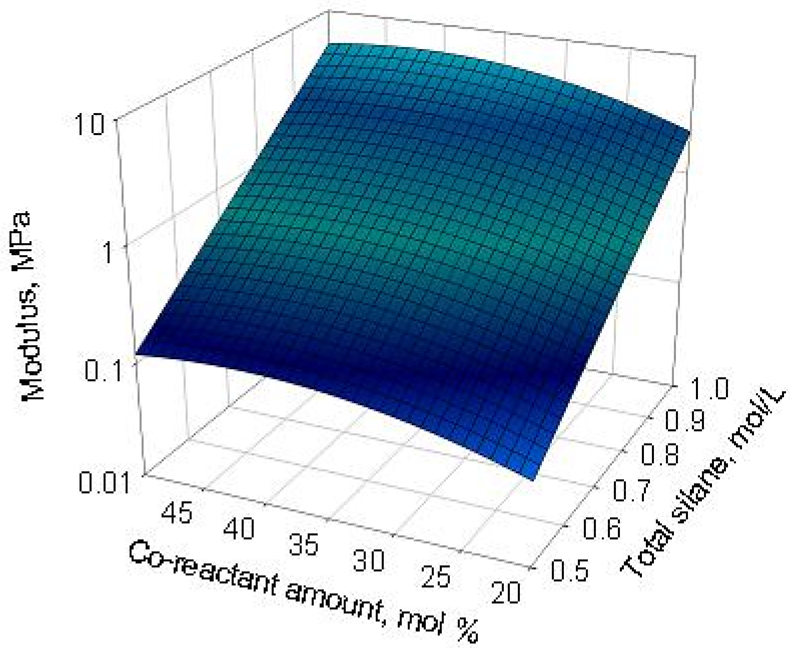
3 Variable DoE Study to assess effects of:

- Am't of total silane (aminopropyl + TMOS0 in initial sol
- Two different co-reactants – APTES and APDMES
- Am't of co-reactant as mole % of total

On:

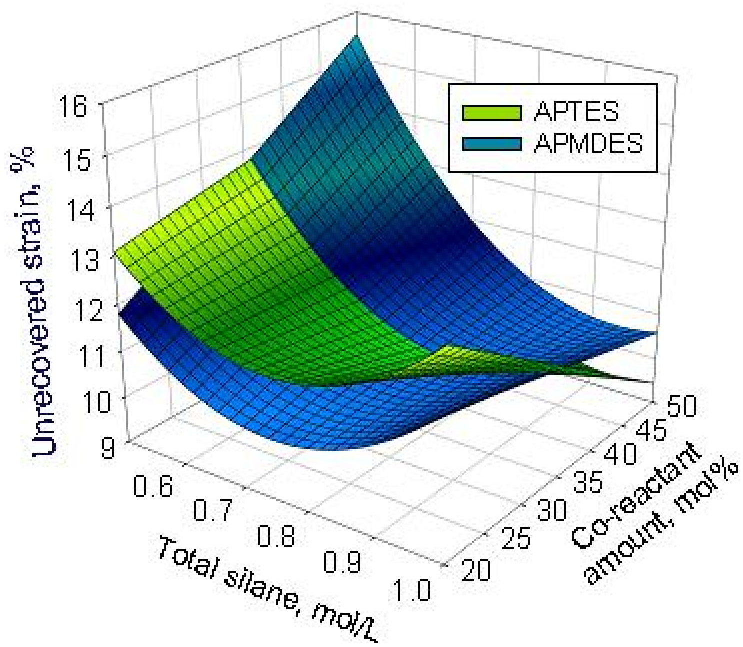
- Density – no effect of co-reactant type, interact of co-reactant and total silane
- Porosity – slightly higher for APTES
- Compressive Modulus – depends on total silane
- Compression Set – APDMES more sensitive to co-reactant %
- TOS – see figure

Compression tests



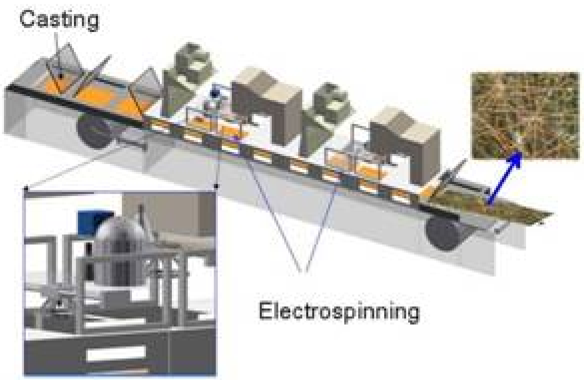
- Modulus dependent mostly on total silane concentration
- No effect of co-reactant type

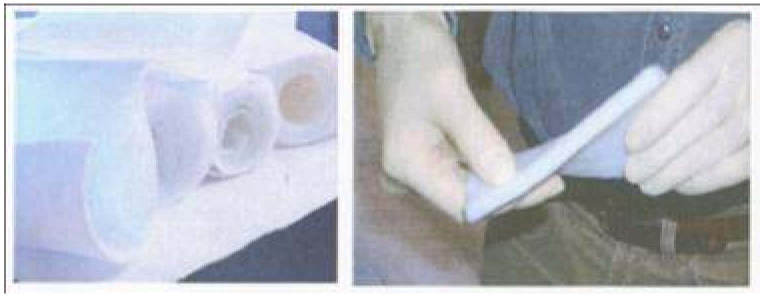
- Samples compressed to 25 % strain and allowed to recover
- APMDES aerogels more sensitive to mole fraction



Development of large scale manufacturing

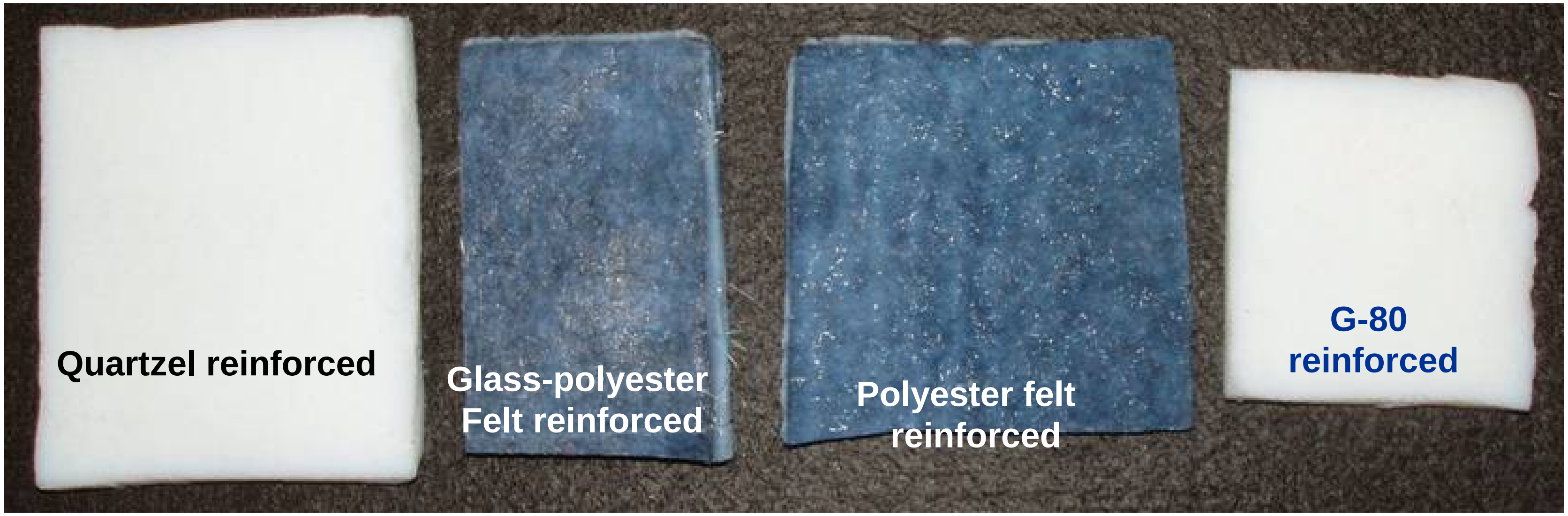
- GATE Platform Technology development
  - Parker-Hannifin
    continuous process to manufacture tubing
  - University of Akron CMPD
    thin film casting, incorporation of electrospun fibers
  - Applied Sciences, Inc.
    incorporation of carbon nanofibers
- Partnership with Aspen Aerogels
  - Aerogel composites
  - Early introduction technology
  - Can solve some issues related to other types of manufacturing





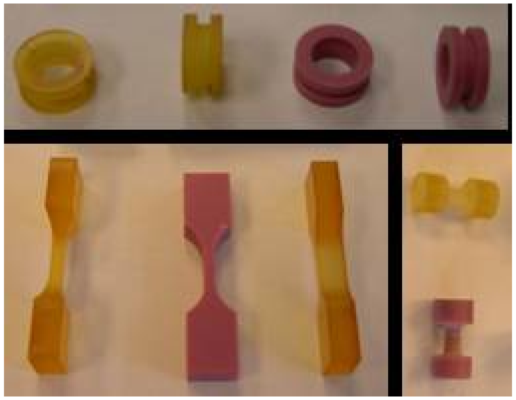
Large Scale Aerogel Manufacturing

joint with Aspen Aerogels

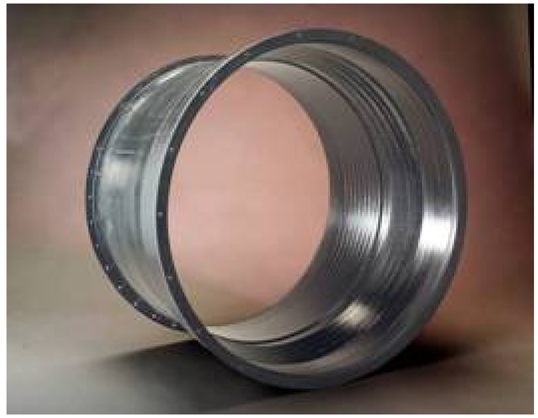


- Thermal conductivities as low as 20mW/mK
- Mechanical properties – TBD
- Cross-linking eliminates shedding

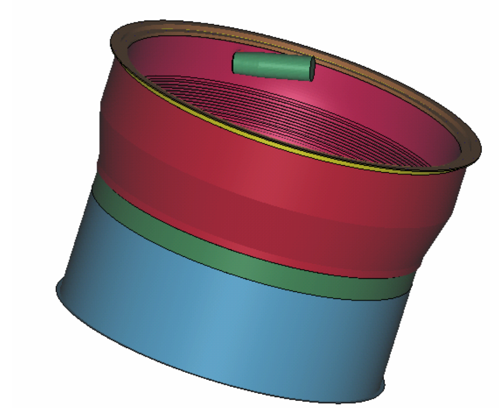
Composite Materials for Engine Containment Cases



Resin Mechanical Tests
- High strain rate constitutive models
- Toughened material evaluation

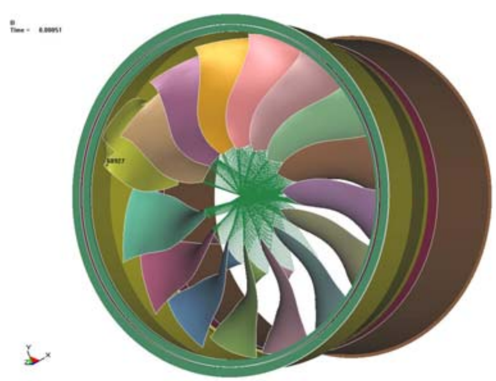


Composite Fan Case Fabrication
- A&P Technology- braided preforms
- North Coast Composites- molding (RTM)

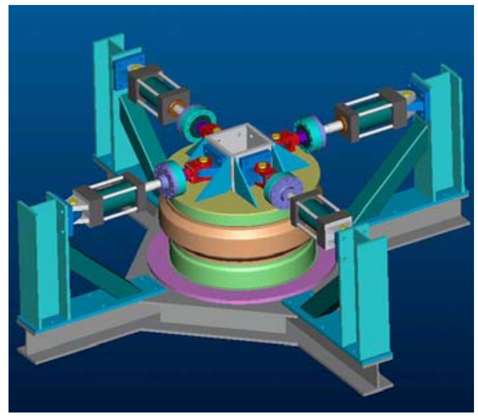


Ballistic Impact Tests: Fan Cases
- Simulate blade impact
- Measures resistance to penetration

Ballistic Impact Tests: Panels
- Materials screening
- Composite material and failure models

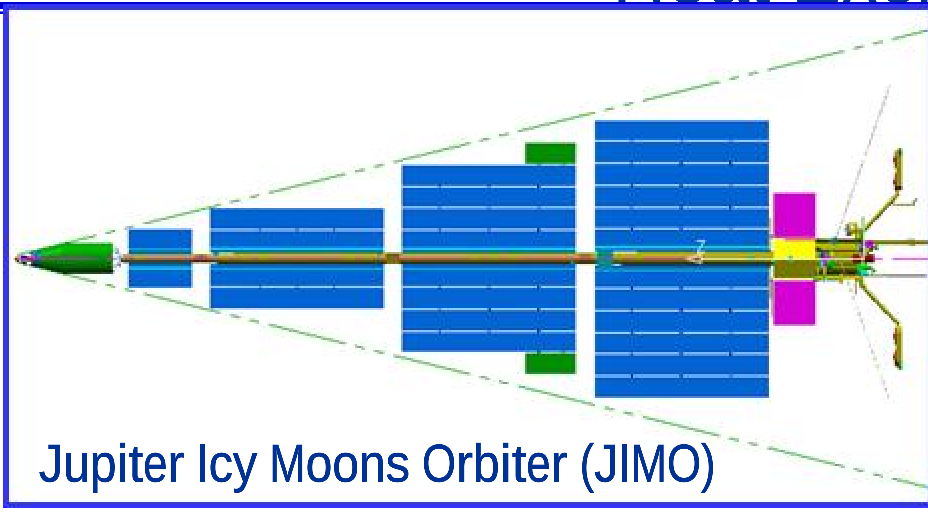


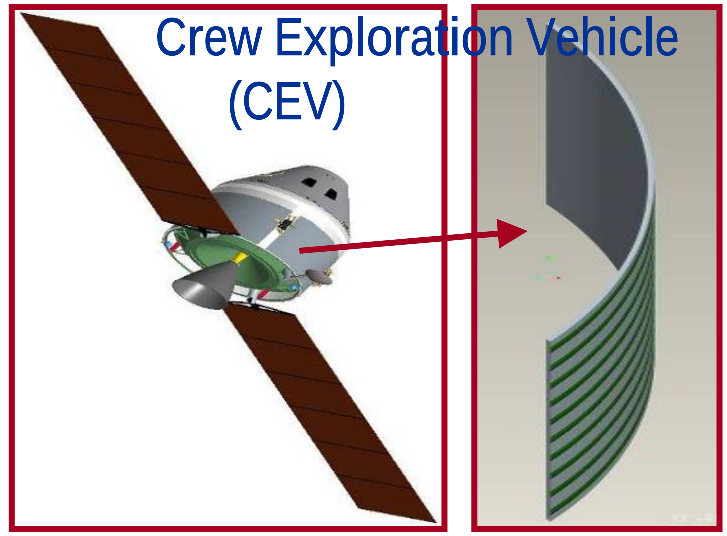
Engine Blade-Out Simulation
- Define ballistic impact test parameters
- Validate analysis methods for certification



Structural Loading Tests
- Simulate rotor out-of-balance loads
- Measures resistance to crack growth

High Temperature PMC Radiators and Heat Exchangers


Jupiter Icy Moons Orbiter (JIMO)


Crew Exploration Vehicle (CEV)

- ✓ Larger area, significant mass driver
- ✓ Wider range of temperatures (200 – 550°F)
- ✓ Sophisticated deployment, possibly similar to ISS

⇩

<u>PMC with high thermal conductivity carbon fibers</u>
<u>(Coal tar pitch-based w/ up to 1000 W/mK)</u>
<u>→ Higher potential!</u>

Fission Surface Power (FSP)

Funding Opportunities

- Aeronautics Mission Directorate NRA
  - http://www.aerospace.nasa.gov/nra.htm
  - Topics already listed for Supersonics and Subsonics Rotary Wing, Subsonics- Fixed Wing expected soon
- SBIR/STTR
  - http://nctn.hq.nasa.gov
  - Phase I- 6 months, $100K; Phase II – 2 years, $600K
  - Dates -TBD
  - SBIR Submission Deadlines - Typically Late Summer/Early Fall
    - 2006 deadline for SBIR Phase I proposals was September 7
- Innovative Partnership Program
  - Started in FY06, expect opportunity in FY08
  - Fund partnerships between NASA Center and industry – emphasis on both commercialization and NASA mission needs
  - Up to $250K funding/year, requires industry and NASA program cost match