Polymer and Nano-Material Research in the Polymers Branch at NASA Glenn Research Center

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Future Exploration Mission Requirements Cannot Be Met with Conventional Materials

Satellites and rovers

- Reduced mass and volume
- Reduced power requirements
- Increased capability, multifunctionality

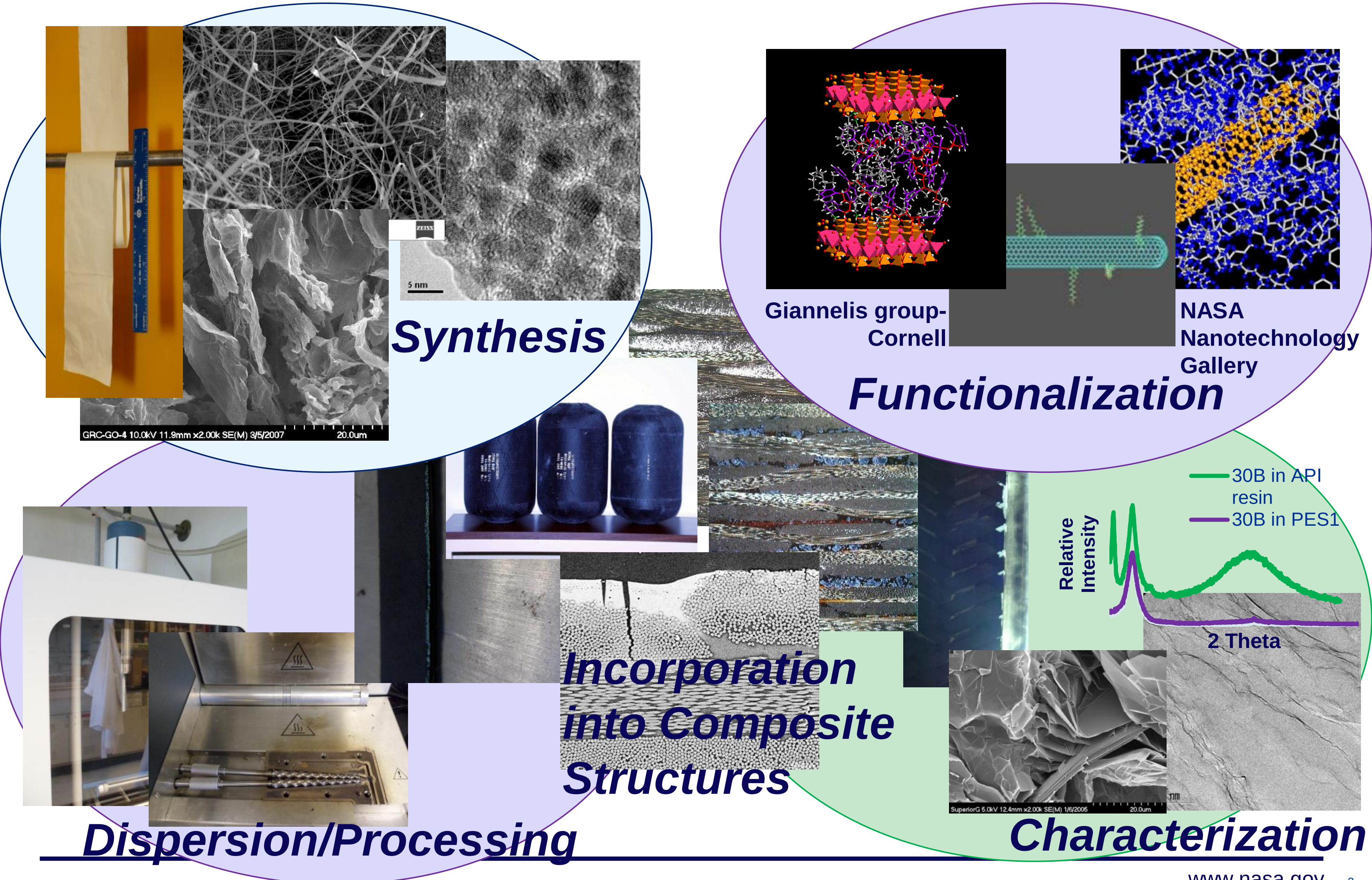
Vehicles and habitats

- Reduced mass
- High strength
- Thermal and radiation protection
- Self-healing, self-diagnostic
- Multifunctionality
- Improved durability
- Environmental resistance (dust, atmosphere, radiation)

EVA Suits

- Reduced mass
- Increased functionality and mobility
- Thermal and radiation protection
- Environmental resistance

RXP Nanomaterials Research



Outline

- Nanocomposites for Highly Loaded Structures
- Nanocomposites for Cold Temperature Applications (cryogen storage)
- Nanocomposites for High Temperature Applications (300^{o}C)

Composite Fan Blade

Goal: Enable Reduced Blade Thickness through Improved Composite Fracture Toughness and Interlaminar Strain

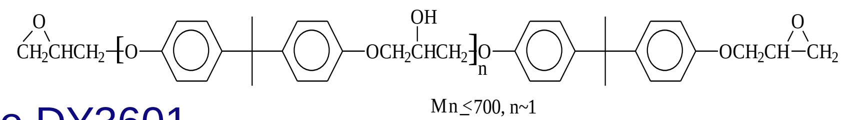
Approach:

1. Investigate the influence of a wide range of nanoparticles on epoxy toughness.
2. Design materials to best utilize the various nanoparticles.

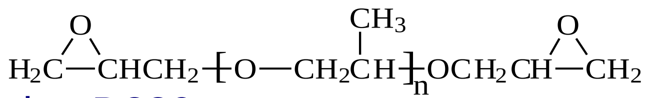
Composite Fan Blades
Background

Materials:

Epon 826

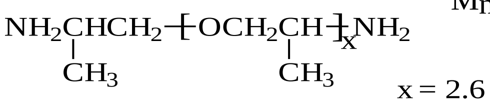


Araldite DY3601

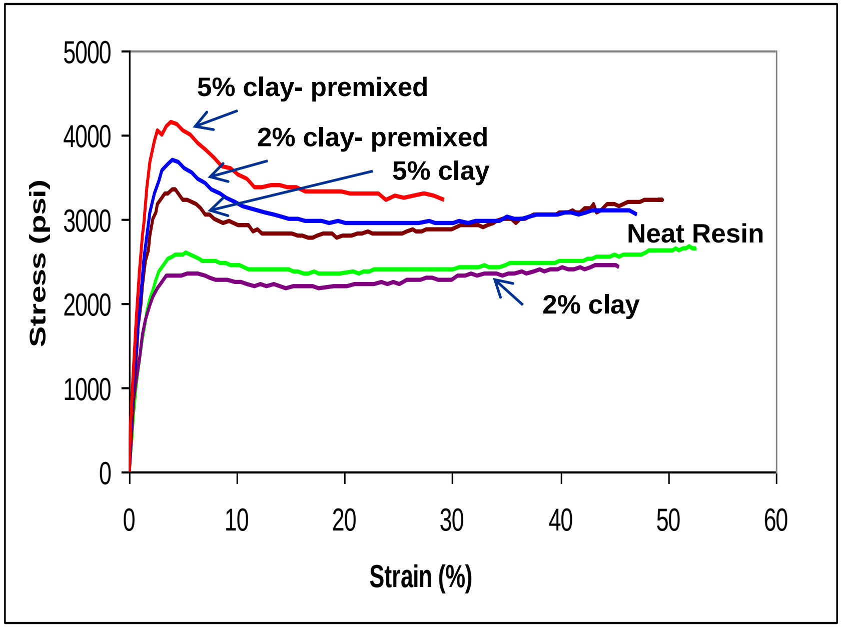


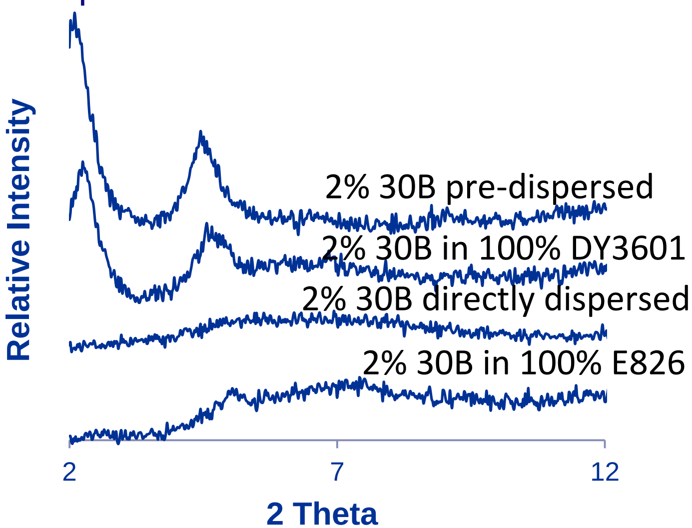
Jeffamine D230

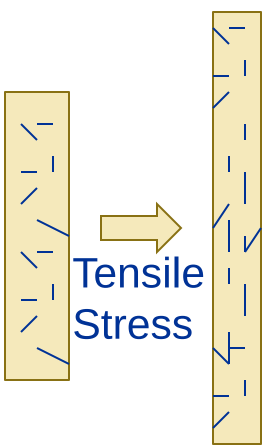
Mn < 385

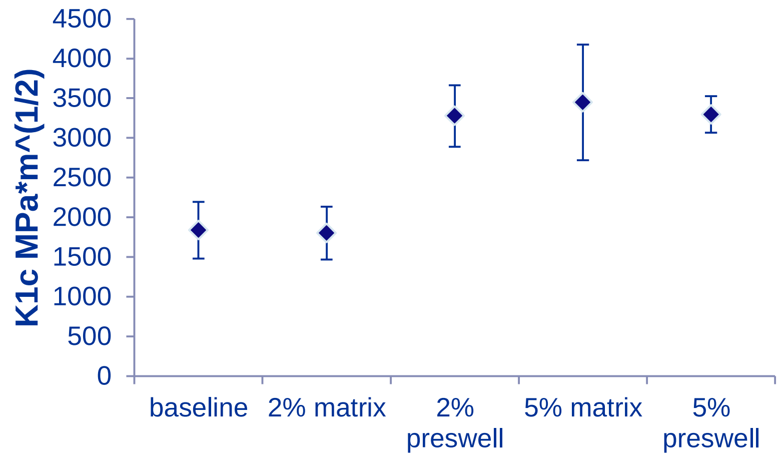


- Tensile strength and ductility are improved when nano-particles can align in the direction of applied load.
- Pre-dispersion forces clay into the more mobile components of the resin.



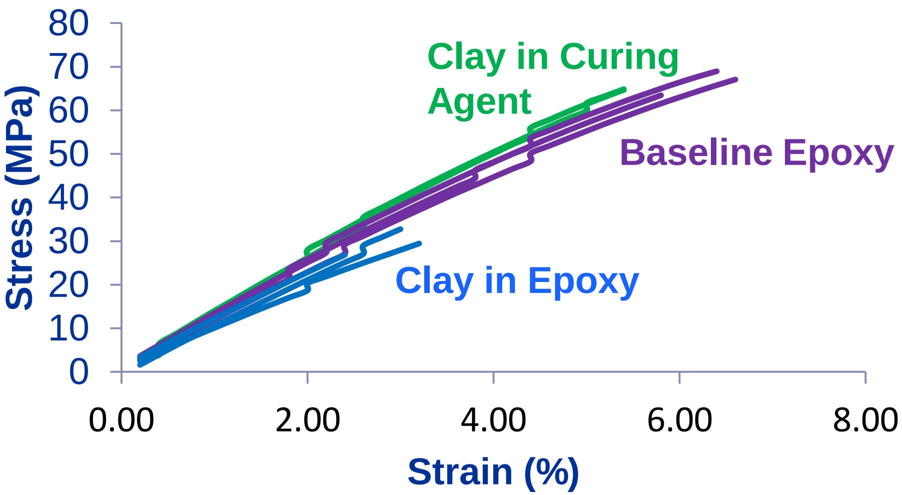




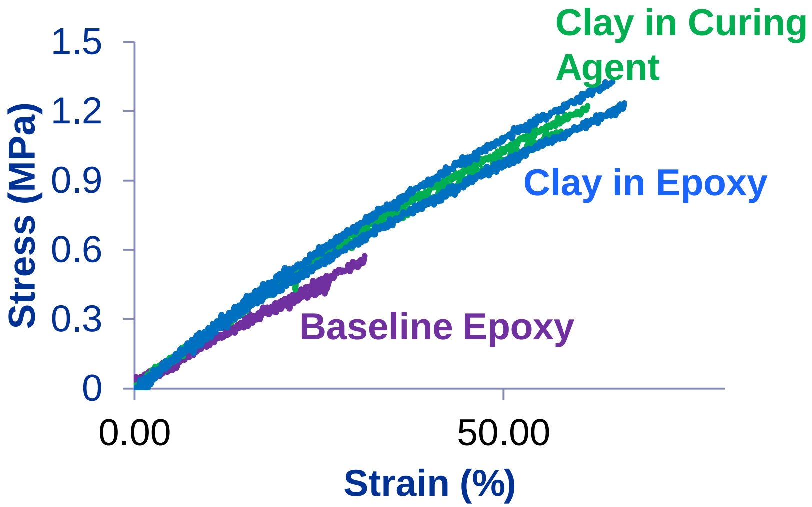


Strain in Un-Toughened Epoxy-Clay Nanocomposites

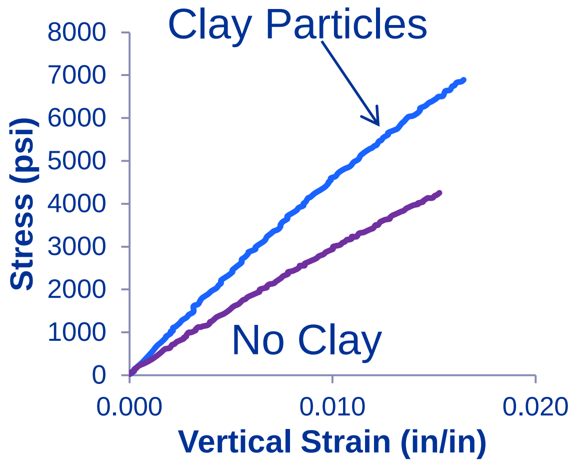
Glassy at Room Temperature

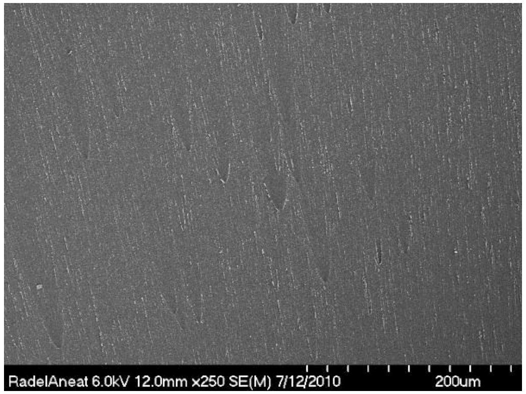


Rubbery at Room Temperature

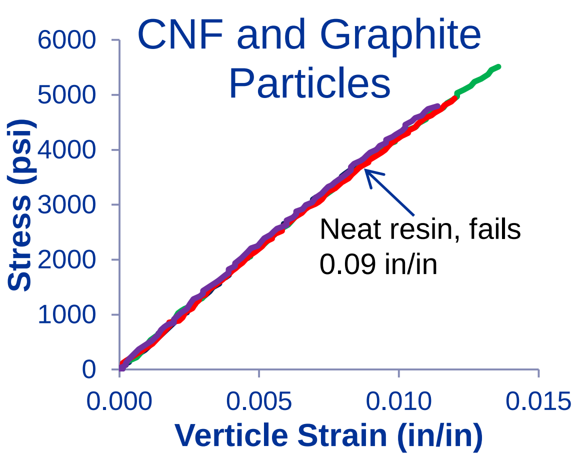


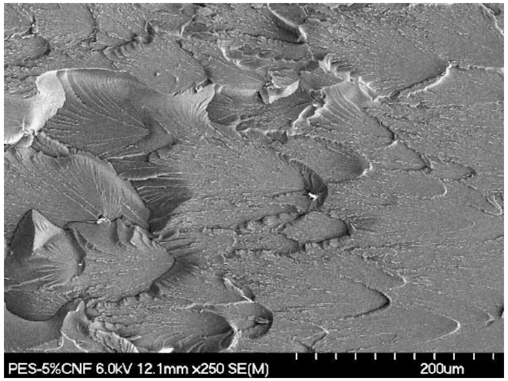
Nanocomposites Based on Aerospace Grade Epoxies

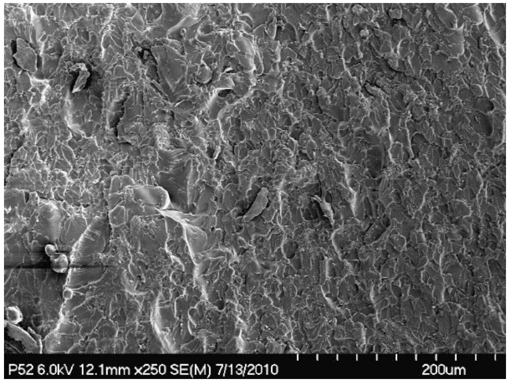




Fracture surface of nano-reinforced samples indicate increased material toughness



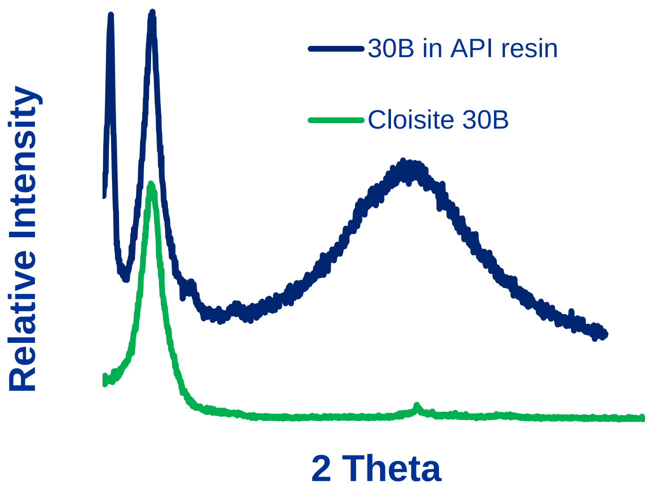




Graphite particles were epoxy functionalized via solvent-based wash. CNF particles were not functionalized.

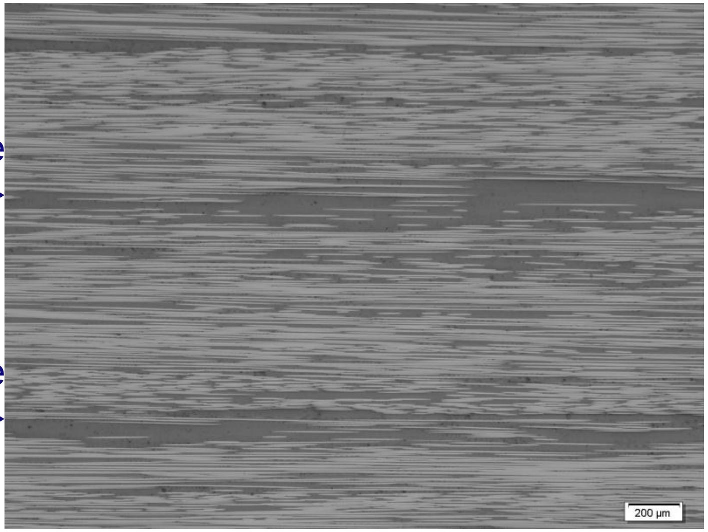
Composite Structures

1. Epoxy Nanocomposite film laid up with between plies of base laminate.
2. Autoclave cured using vendor recommended cure cycle
3. Characterized for panel quality
   1. C-scan
   2. Acid Digestion
   3. Optical Microscopy
4. Mechanical Testing



Resin Interleave

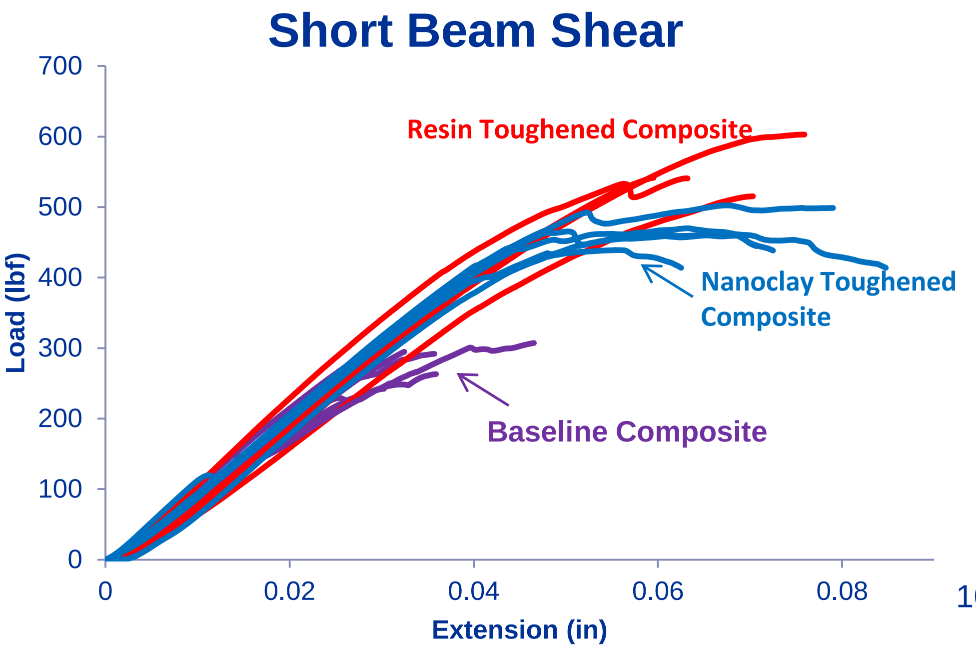
Resin Interleave



Photomicrograph of SBS test coupon, $[0]_{16}$ lay-up, along fiber direction

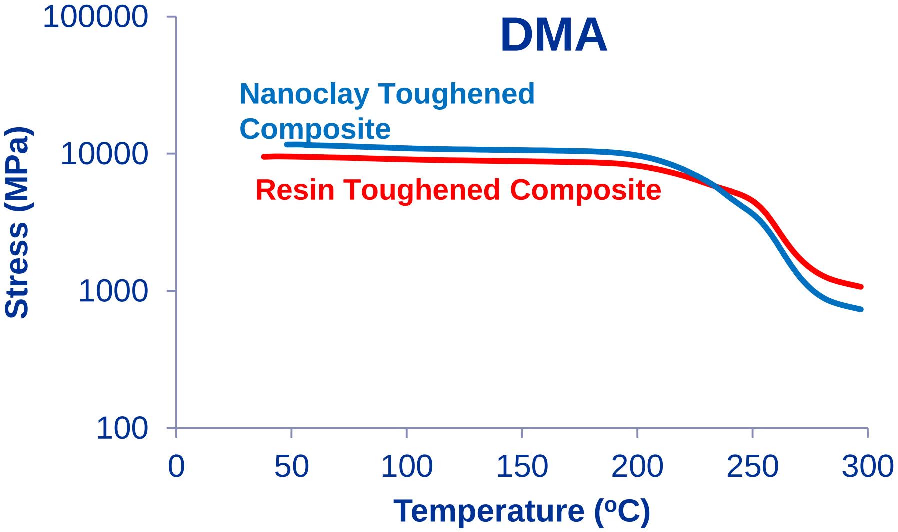
Composite Testing: Thermal and Mechanical

Testing Results



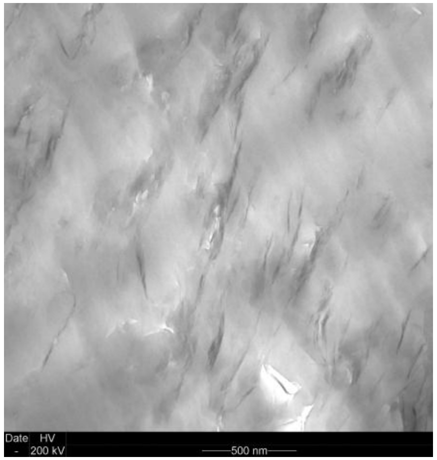
Nanoclay interleave shows drop in short beam shear strength, but comparable or improved ductility

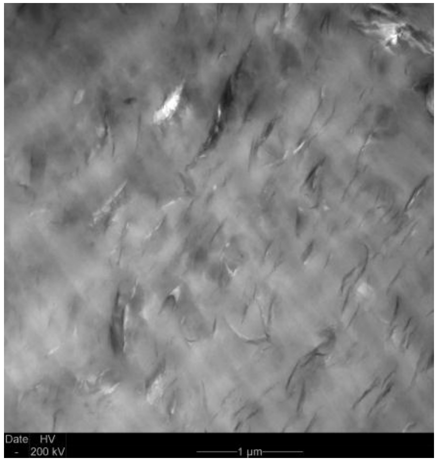
Little difference in dynamic mechanical data.



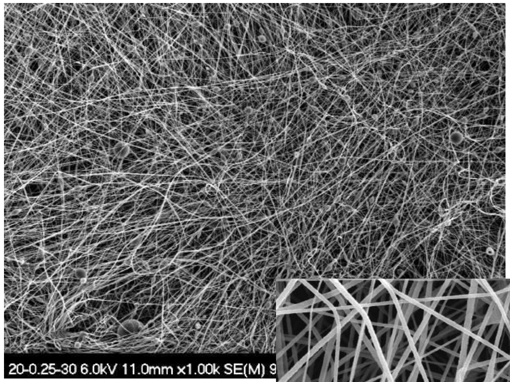
Next Steps - Improved Nano-Incorporation

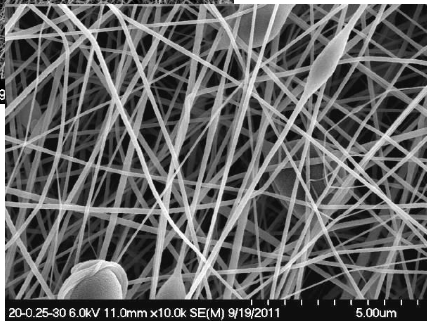
- Need Better Dispersion
  - Do not have the facilities to handle this scale of dispersion.
  - Contract in place with Nanosperse to aid in dispersion





- Exploring Alternative Mechanisms to Include Nanoparticles
  - Purchases in place with Nanocomp to incorporate CNT sheets
  - Working with North Carolina A&T University to electro-spin PES for interleave material.

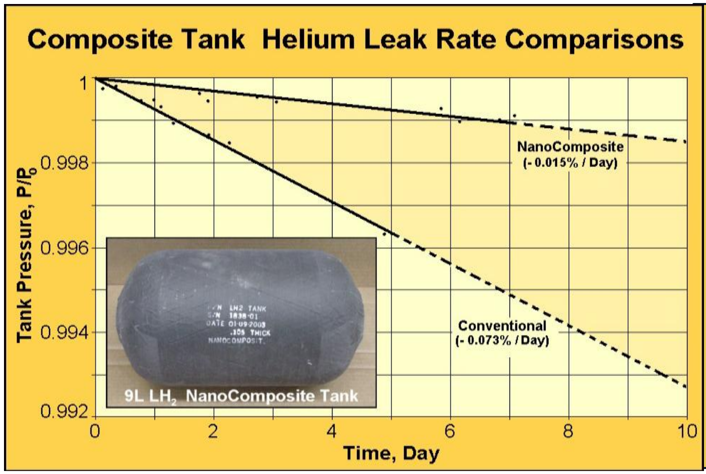




Composite Tanks

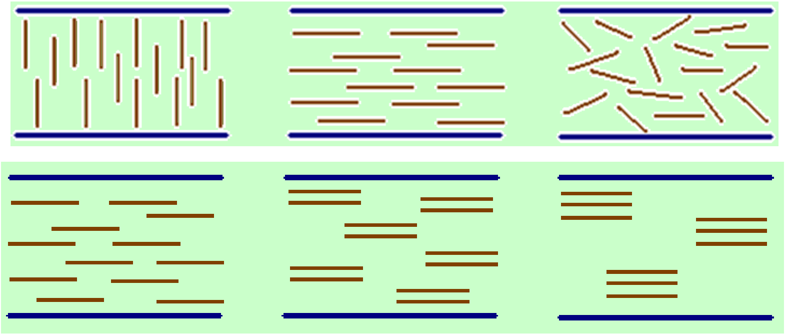
Goal: Reduce Permeation through Composite

- The majority of this effort has focused on clay nanoparticles.
- Reduced material permeability following nanoclay dispersion is well documented.
- Expected that the platelet structure of clay contributes to the improved barrier performance.



5% clay in epoxy matrix lead to a 70% reduction in helium leak rate compared to the baseline tank.

Clay layer dispersion and alignment, with respect to the permeation direction, greatly influence the barrier performance of the matrix



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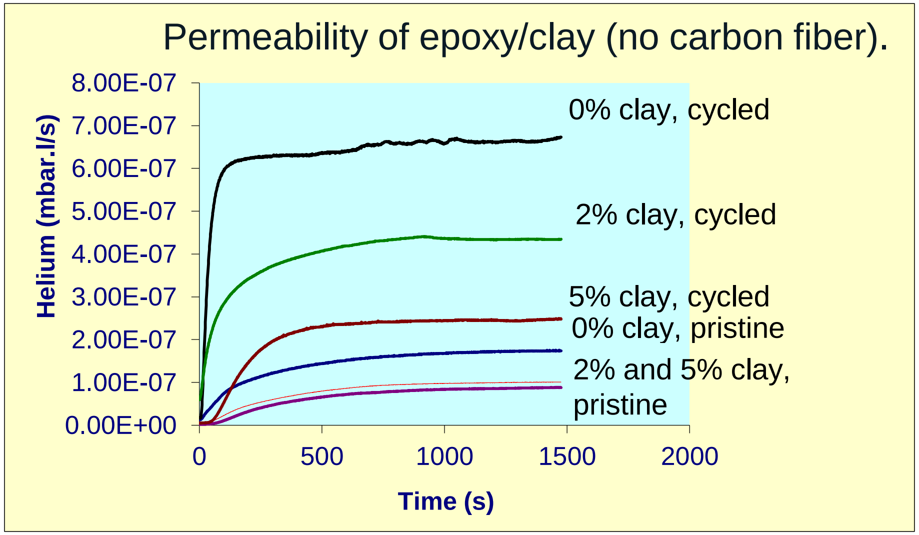
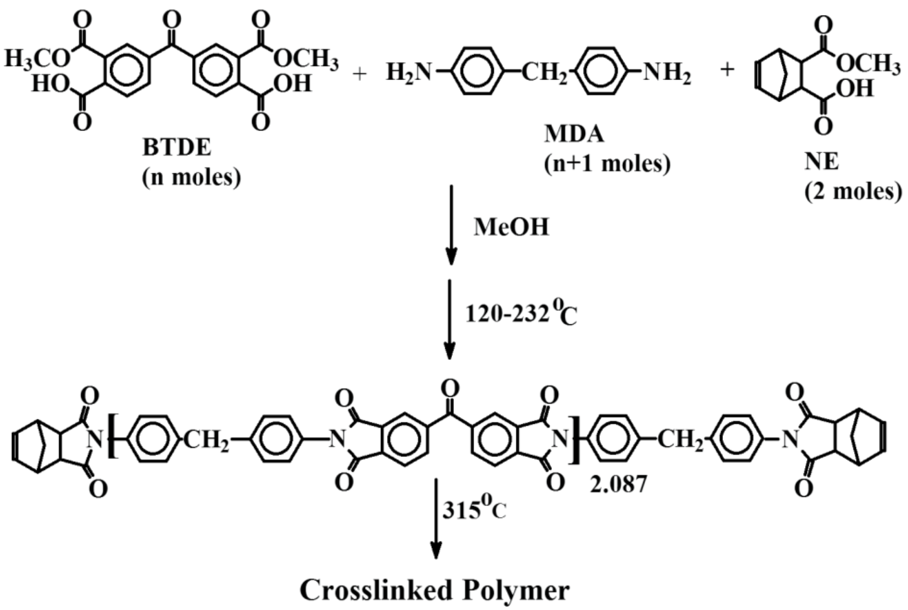
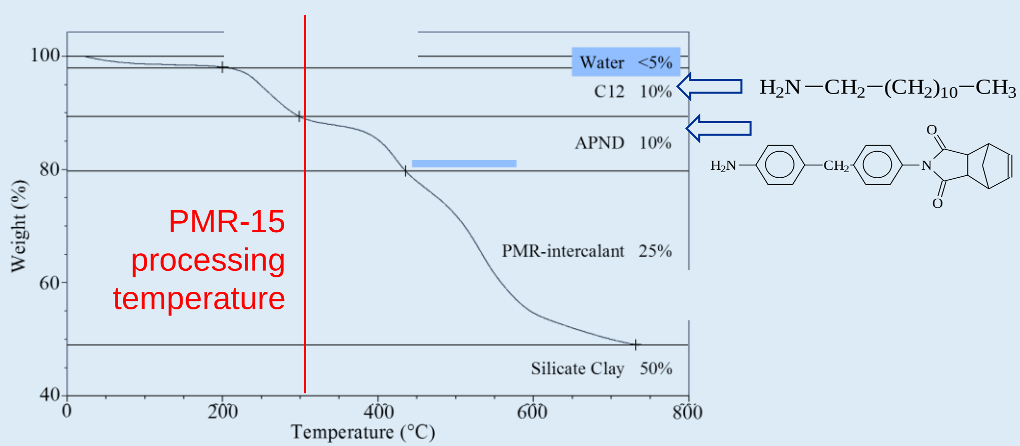


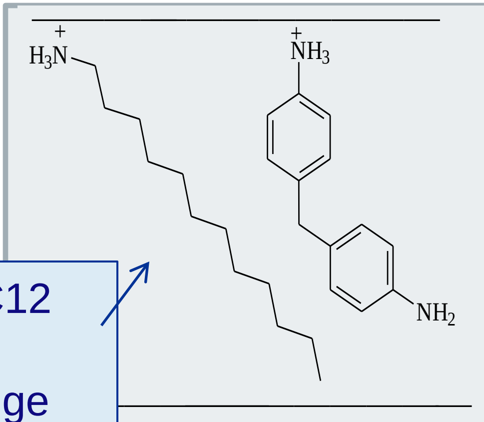
High Temperature Polymer Nanocomposites

Goal: Improve High Temperature Durability of Matrix Resin



Elevated PMR-15 processing temperatures led to development of unique nanoclay modifier.



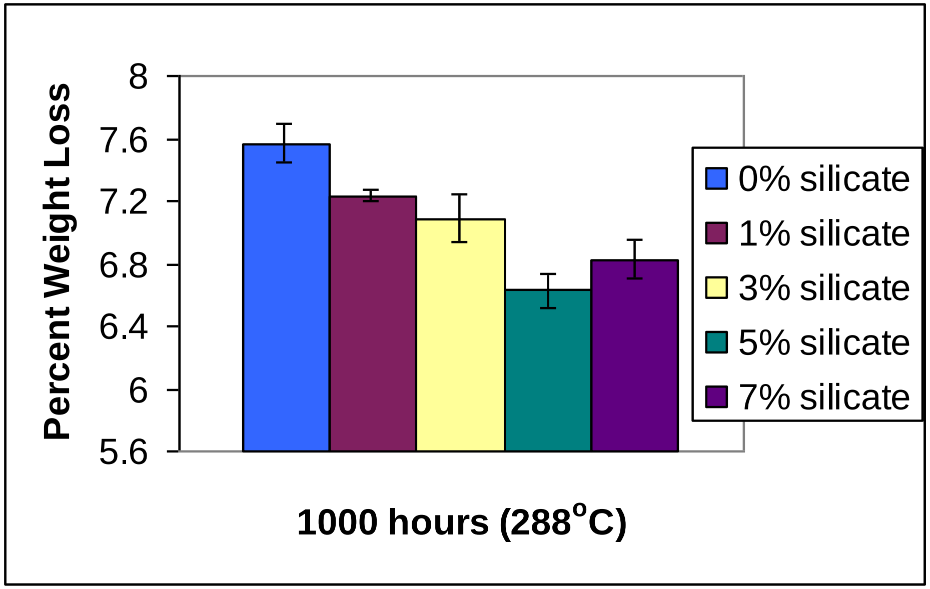


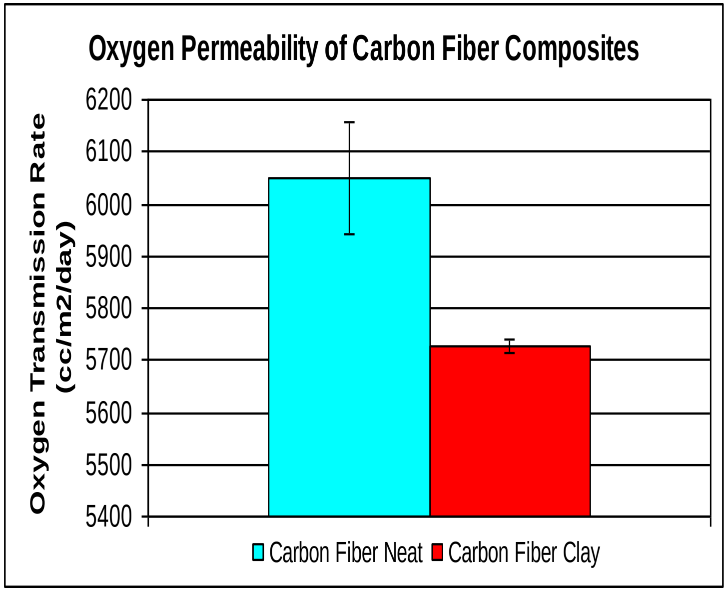
MDA-C12 co-ion exchange

Thermal and Physical Properties of PMR-15/Clay Nanocomposites

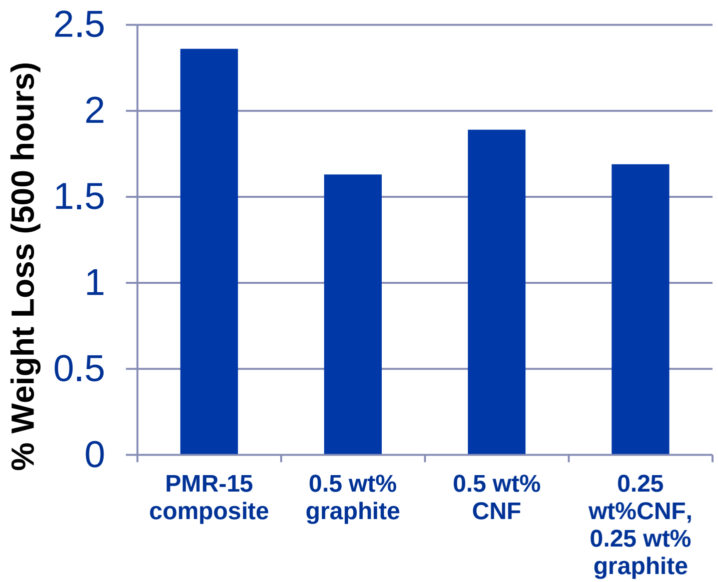
Silicate	PGV-(MDA-C12)	PGV-C12
0%	**335**	**335**
1%	336	337
3%	340	326
5%	337	321
7%	338	311

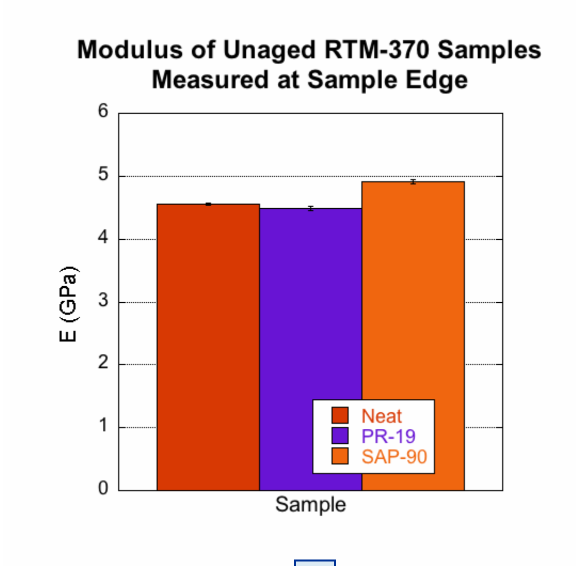
- Glass transition temperature was maintained with increased clay loading.
- Weight loss with thermal aging reduced with increased clay loading.
- Oxygen permeation through nanocomposite reduced compared to baseline material.

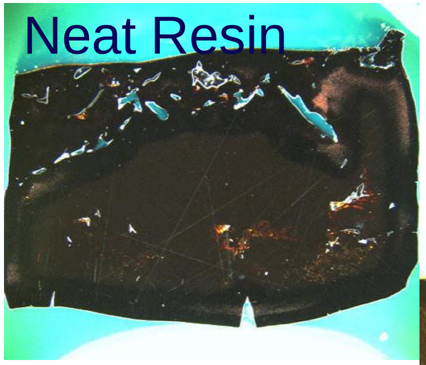




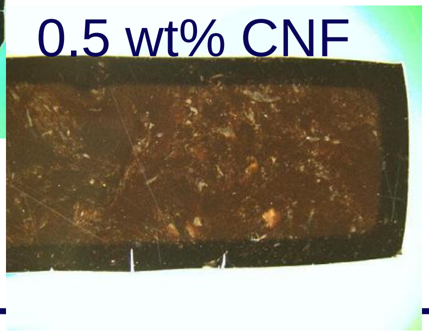
High Temperature Polymer Nanocomposites





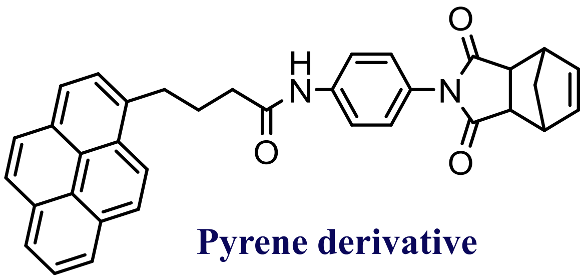


CNF dispersion results in weight loss comparable to clay

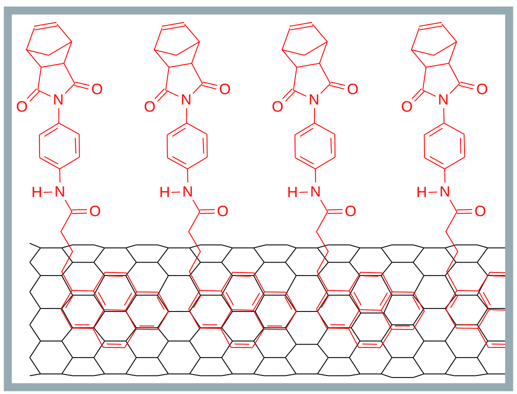


Carbon Nanotube Efforts- Focus on Functionalization

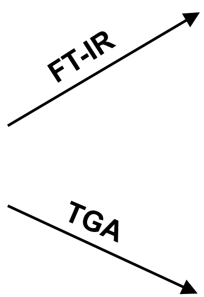
SWCNTs Non-Covalent Functionalization

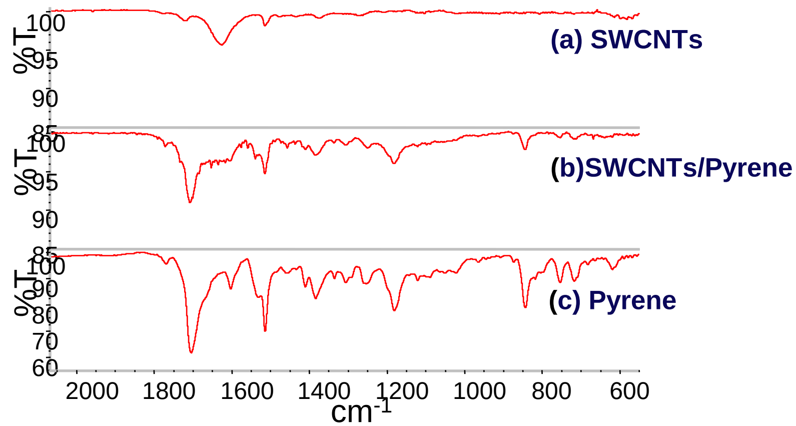


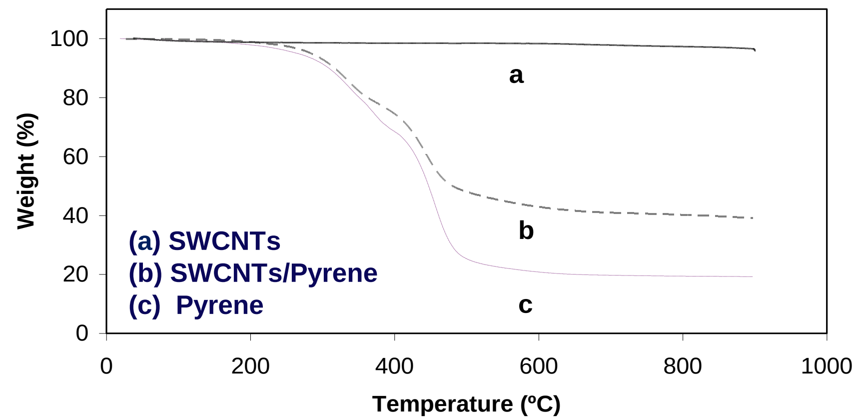
Pyrene derivative



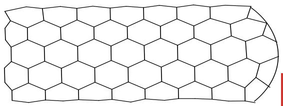
Schematic illustration of the SWCNTs/Pyrene complex



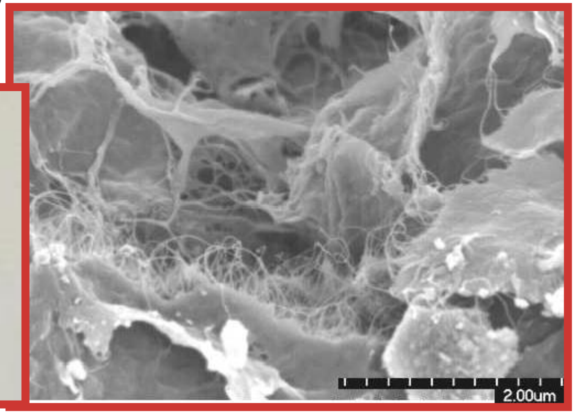




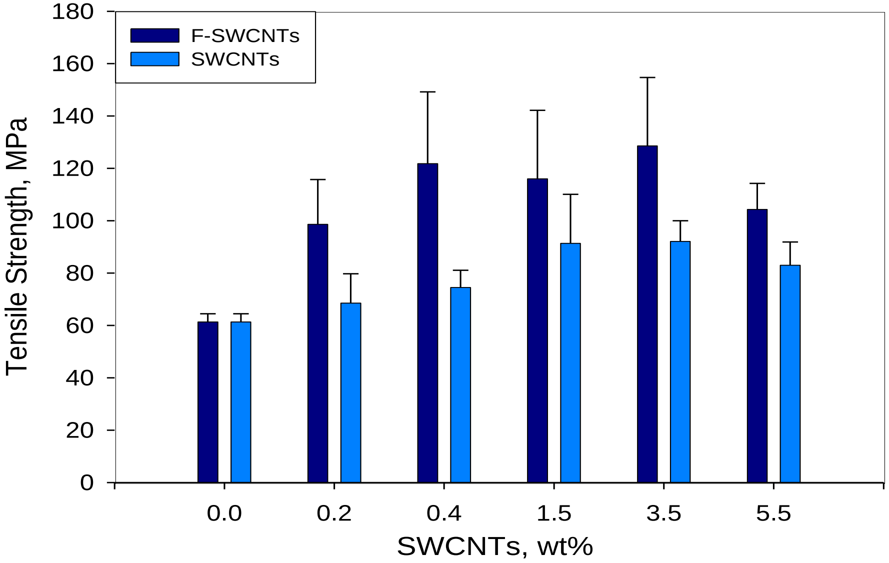
SWCNTs Non-Covalent Functionalization

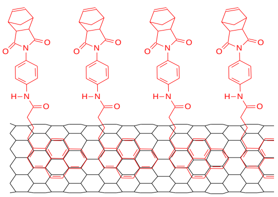


SWCNTs

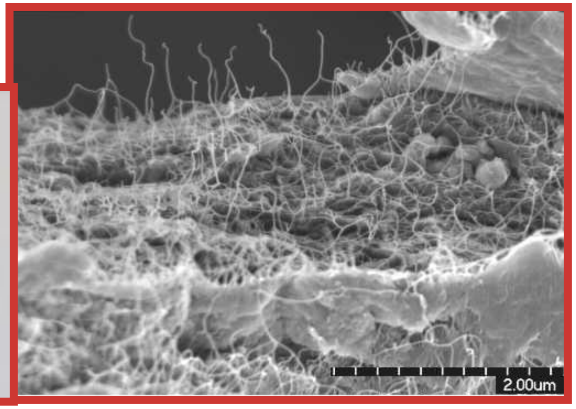


Agglomeration of SWCNTs is clearly visible in the SEM image of the SWCNT nanocomposite film.

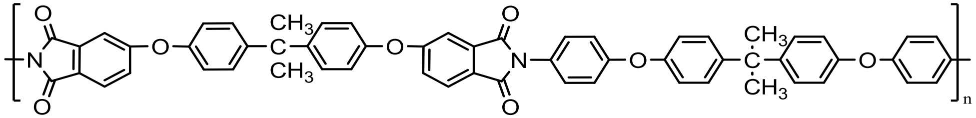




SWCNTs complex



The addition of 3.5 wt% SWCNT/complexes increased the tensile strength of the polyimide from 61.4 to 129 MPa; higher loading levels led to embrittlement and lower tensile strengths

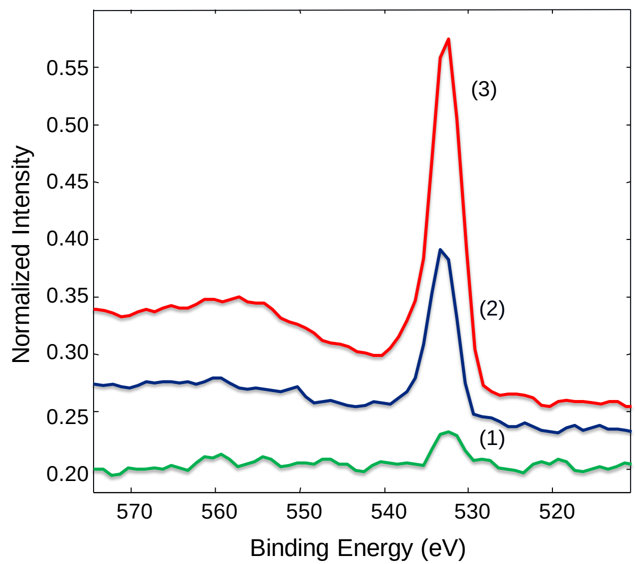


BPADA/BAPP

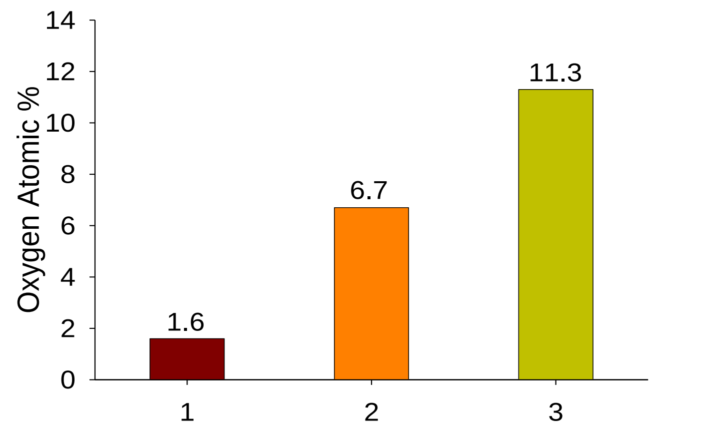
Complexes form stable colloidal dispersion in polar solvents –enables production of homogeneous polymer films.

Results: Photo-Oxidation of SWCNTs

- The oxygen content of the SWCNTs (i.e., photo-oxidation, acid treatment) has been studied by X-ray photoelectron spectroscopy (XPS).
- **Photo-oxidation adds nearly 2X the oxygen to the SWNTs than acid treatment alone.**



(a)

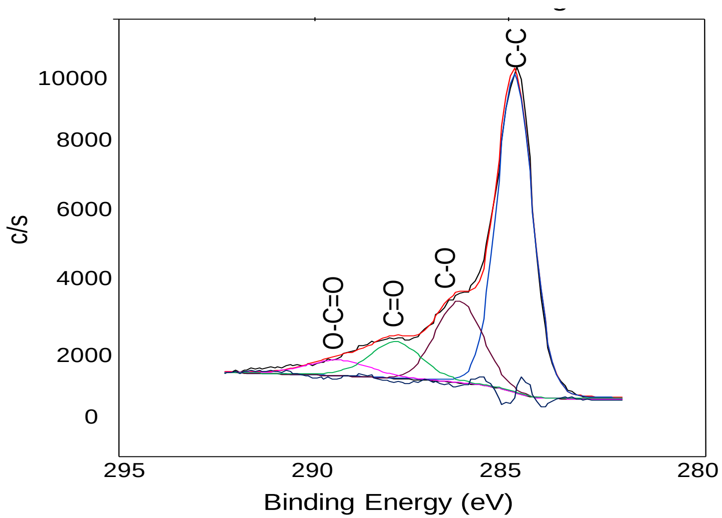


(b)

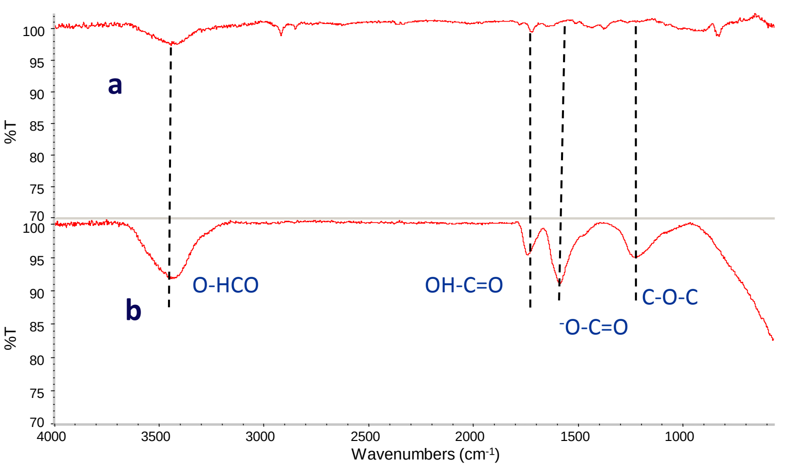
(a) Overlay of oxygen peaks from the survey scan after normalizing the carbon peaks.
(b) Oxygen concentration of SWCNTs oxidized by photo-oxidation (with and without sensitizer) and by acid treatment.

Results: Photo-Oxidation of SWCNTs

- XPS is sensitive to matrix effects and is able to provide both oxidation and chemical state information about the elements detected.
- An overlay of all of the carbon regions after normalization revealed the presence of a shoulder on the main carbon peak (284.8 eV) of the photo-oxidized
- Peaks at 286.3 eV, 287.9 eV, and 289.3 eV are indicative of C-O, C=O, and O-C=O, respectively.
- Analytical characterizations by FT-IR also confirmed the presence of oxygen groups.



XPS: Curve-fitting of the carbon region of the photo-oxidized SWCNTs with RB.



FT-IR: (**a**) SWCNTs and (**b**) photo-oxidized SWCNTs.

Additional Nanomaterials Efforts

- Magnetic nanoparticle synthesis and dispersion
- Nanoparticle influence on shape memory polymer
- Nanoparticle modified carbon fibers
- Boron Carbide Nanotube materials (radiation shielding)
- Graphene nanocomposites for improved electrical conductivity.