Application of Chemistry in Materials Research at NASA GRC

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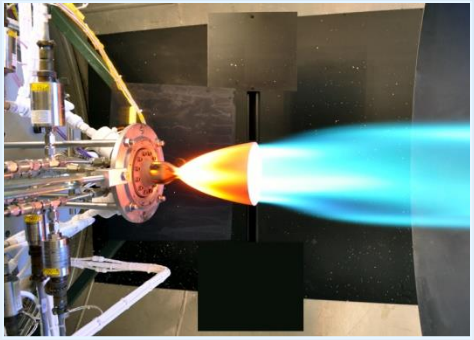
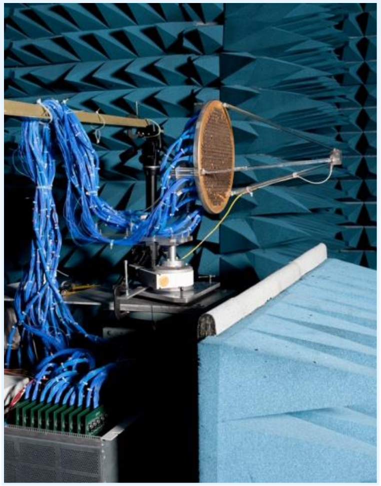
GRC Core Competencies

Air-Breathing Propulsion



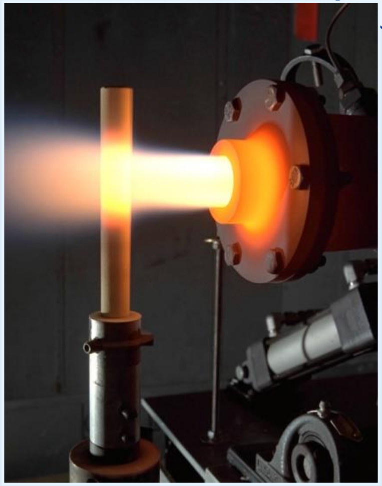
In-Space Propulsion and Cryogenic Fluids Management

Physical Sciences and Biomedical Technologies in Space



Communications Technology and Development

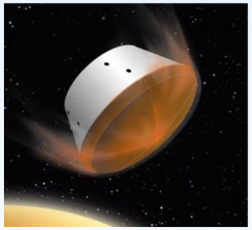
Power, Energy Storage and Conversion



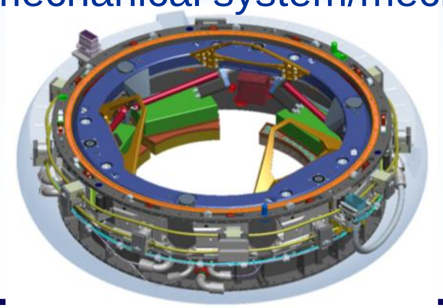
Materials and Structures for Extreme Environments

Materials Research Driven by Key Aerospace Challenges

Higher temperature and harsh environment for aerospace propulsion and planetary entry



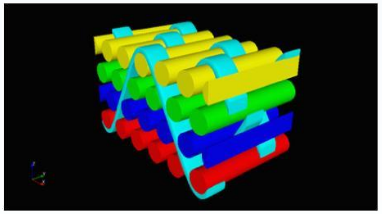
Lightweight and durable mechanical system/mechanisms



Lightweight requirements for large structures

Long-term durability in harsh environments

Low carbon and low emission aircraft

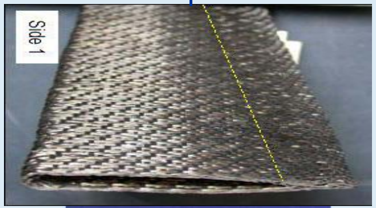


Computational modeling across multiple length scales

Materials Research at GRC

High Temperature Materials

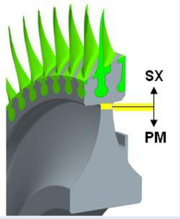
Ceramic Matrix Composite



Protective Coatings

Th

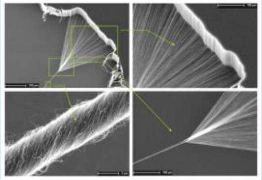
Hybrid Disk



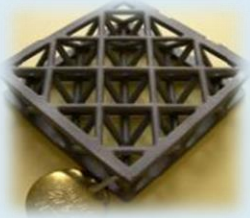
Lightweight Materials

Hybrid Composite Gear

Nanotube Yarn



Lattice Block



Flexible Aerogel

Power System Materials

Materials for High Power Density Electric Motors

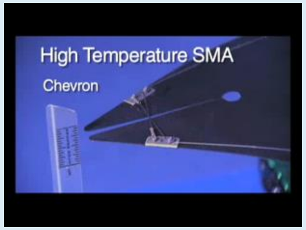
Lightweight Power Transmission Cable

Solid Oxide Fuel Cell Material

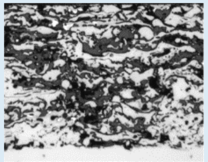
Mechanical System Materials

High Efficiency Gear

Shape Memory Alloy

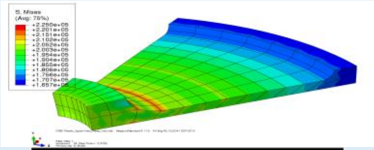


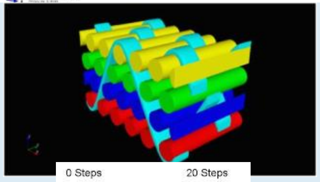
High Temperature Lubrication Coating

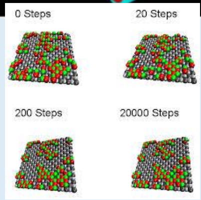


Seal Materials

Computational Modeling

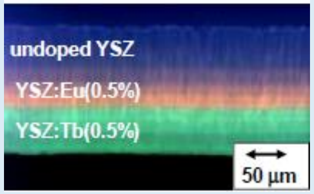




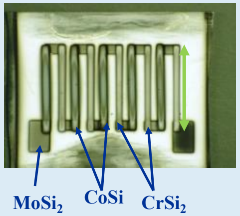


Sensor Materials

Luminescence Coating

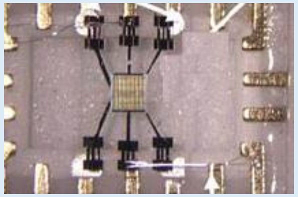


Energy Harvesting for Sensor



Pressure Sensor

Nox and CO Sensor

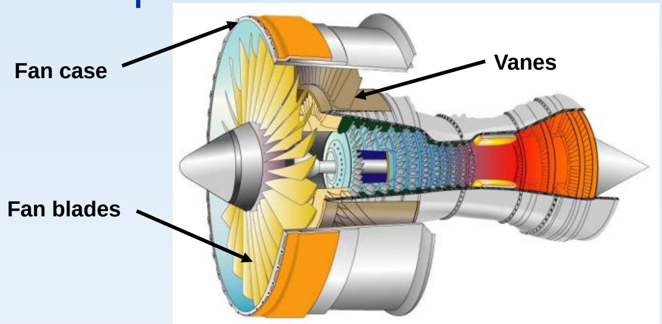


Role of Chemistry in Material Development

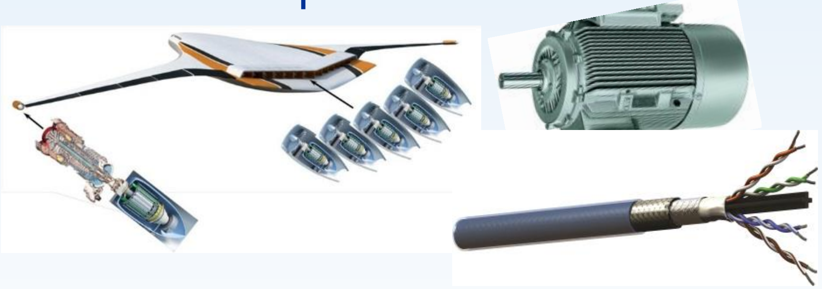
- Polymer science
  - Polymer nanocomposites
  - Aerogels
- Chemical synthesis of materials
- Multifunctional materials based on nanotechnology
- Sensor materials
- Degradation of materials due to reaction with operating environment

Application of Polymers in Aerospace

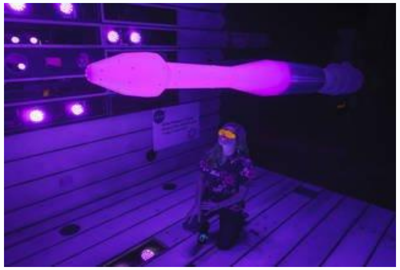
Turbine Engine Polymer Composite Components



Electric Components in Electric Aircraft

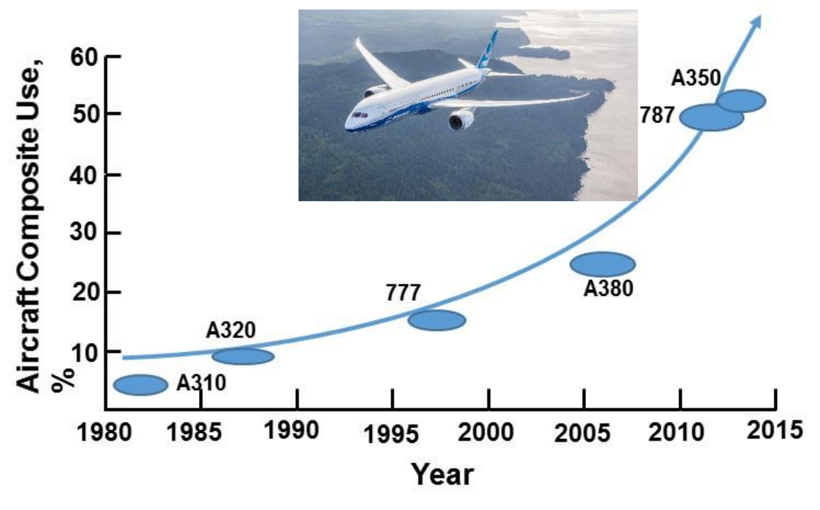


Sensors

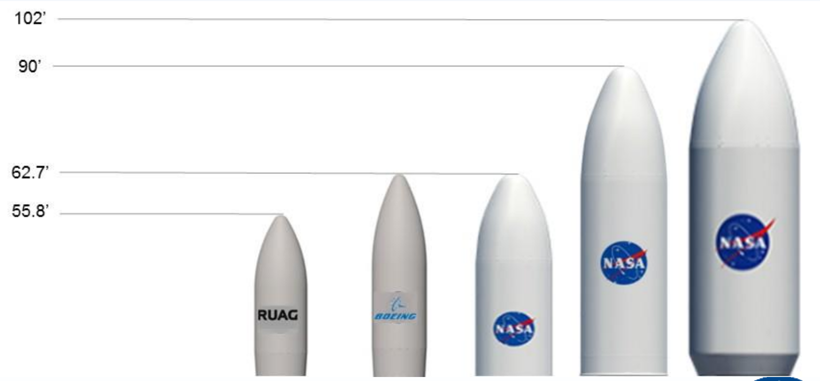


Thermal Insulation

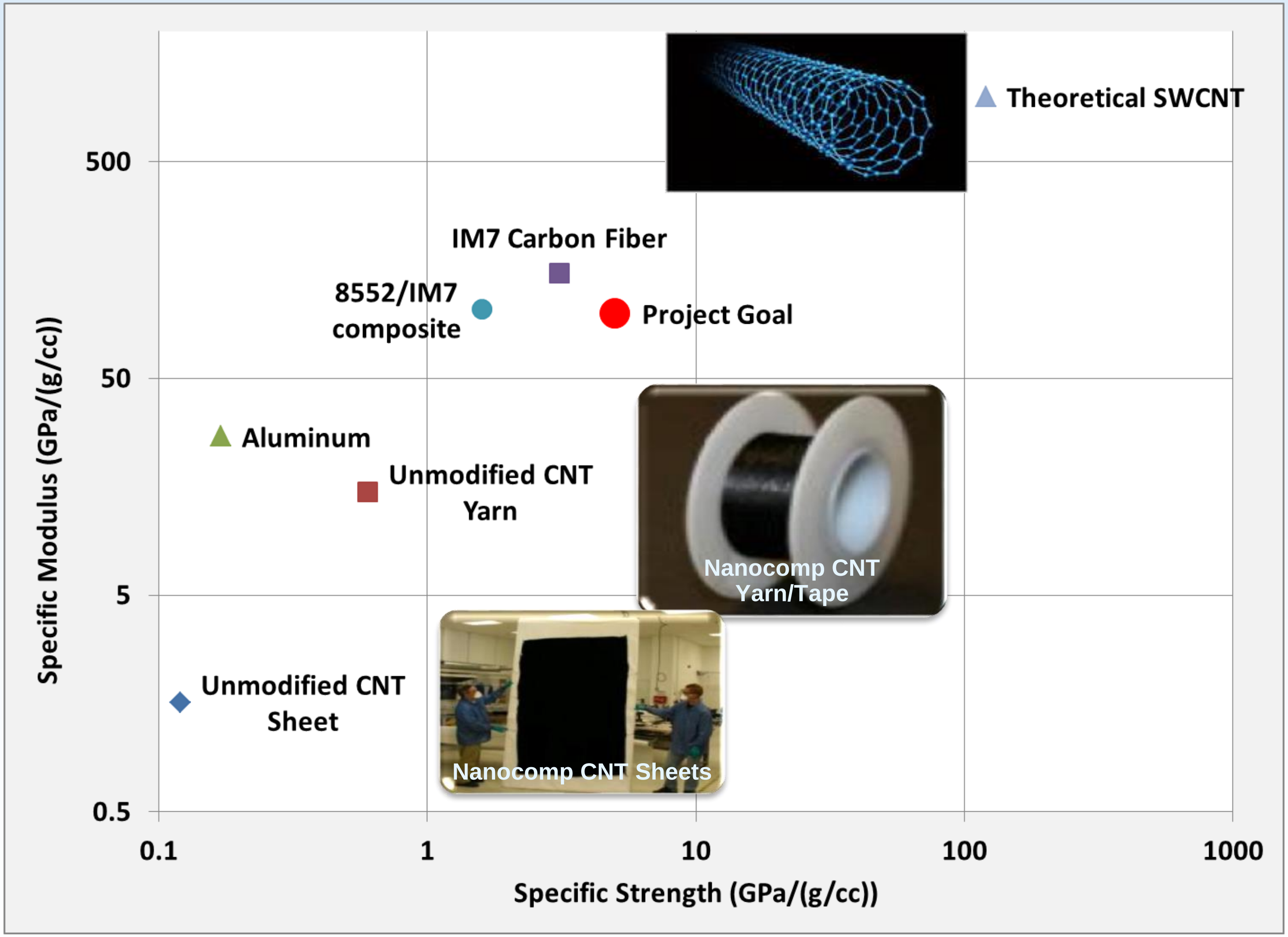
Polymer Composite Aircraft Structure



Polymer Composite Space Structures

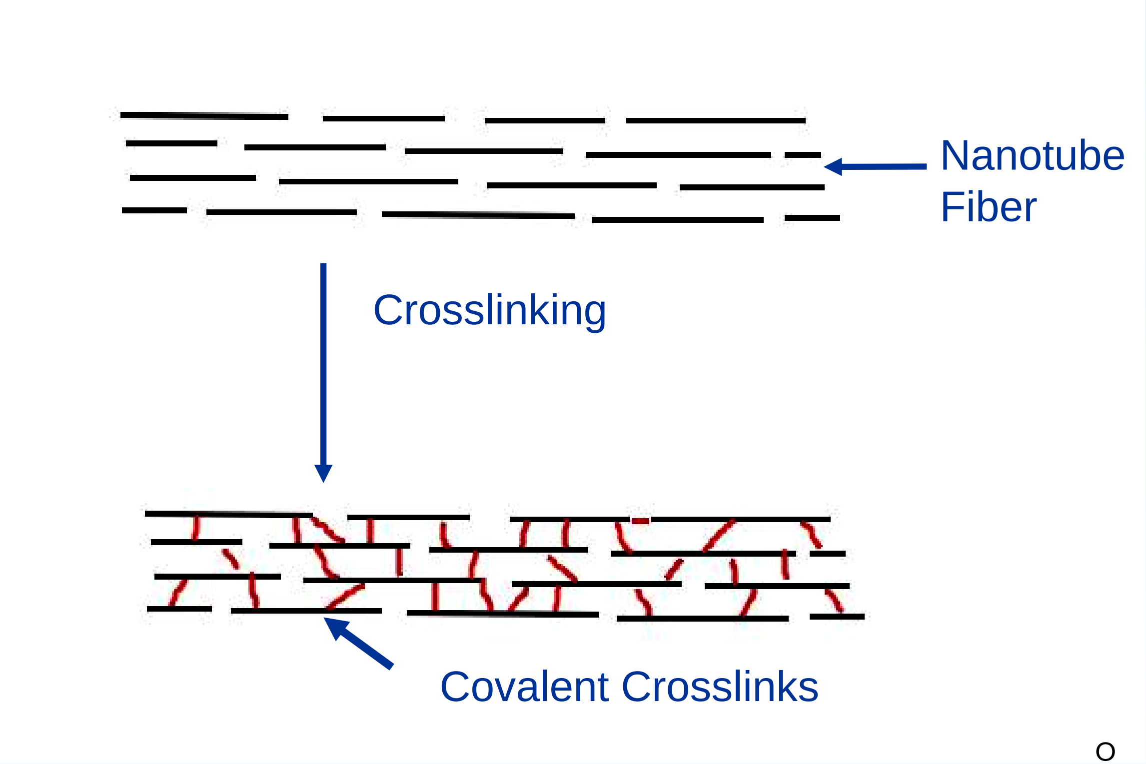


Carbon Nanotube(CNT) -Reinforced Polymer Matrix - Next Generation of Structural Composites



Commercially available CNT-based fibers, yarns, and sheets have significantly lower strength and modulus compared to carbon fibers

Approach to Increase Strength of CNT Nanofiber and Nanosheets

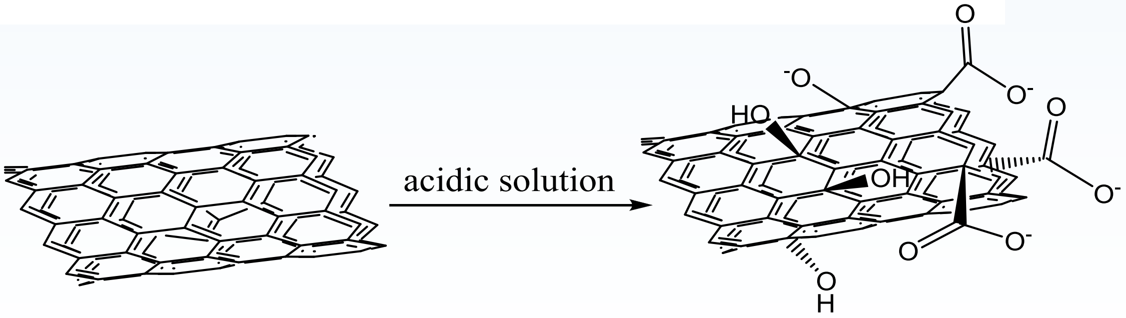


Create covalent, inter-tube bonds to prevent tube-tube sliding.

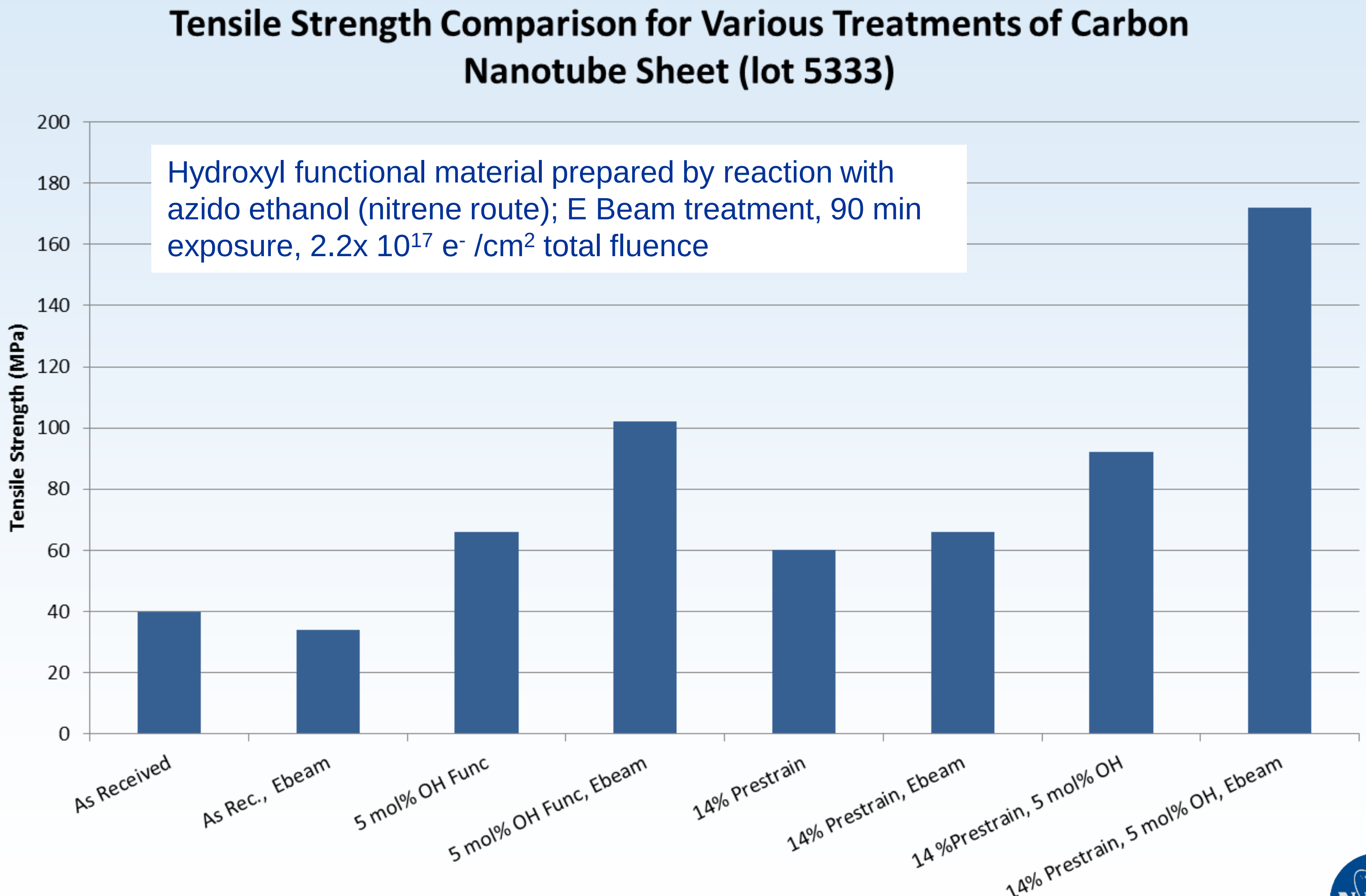
- Chemical modification
- Electron beam irradiation

Increase inter-tube contact and alignment

- Solvent densification
- Stretching

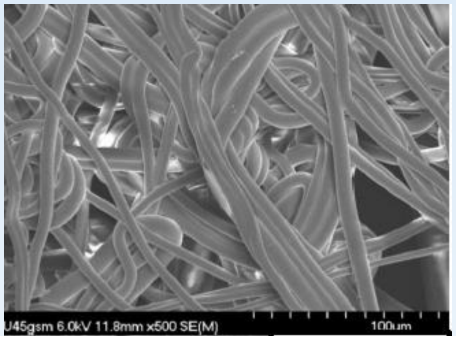


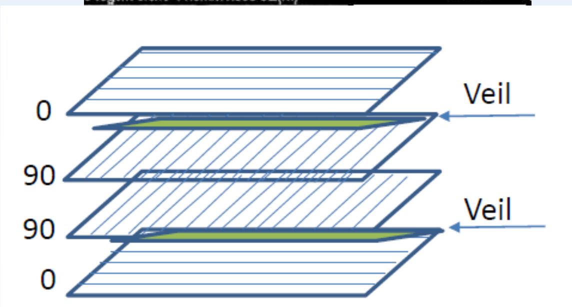
Improvements in Strength of CNT Sheets Through Combination of Post-Processing Treatments



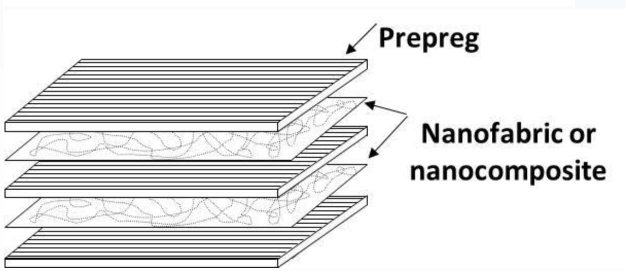
Toughness Improvement of Polymer Composites Through Incorporation of Nanofabric

Thermoplastic Polyurethane Veil





Veil interleaved at cross-plies



Impact Dynamic Testing Simulating Bird Strike in Turbine Engine Fan Blade

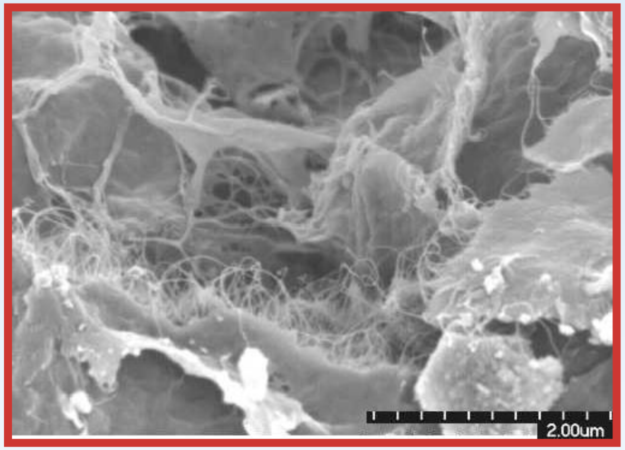
Polymer Composite with no Interleave Veil

Polymer Composite with Interleave Veil

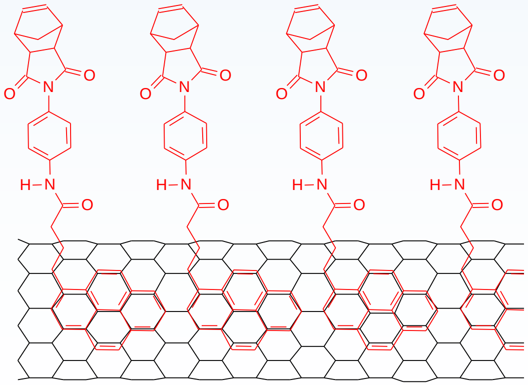
Nanotube Reinforced Polymer Composites

- Nanotube reinforced composites offer unique properties
  - Tailored thermal and electrical properties
  - Decrease in gas permeability
  - Increase in toughness
- Fabrication challenges
  - Uniform distribution of nanotubes in polymer
  - Alignment of nanotubes

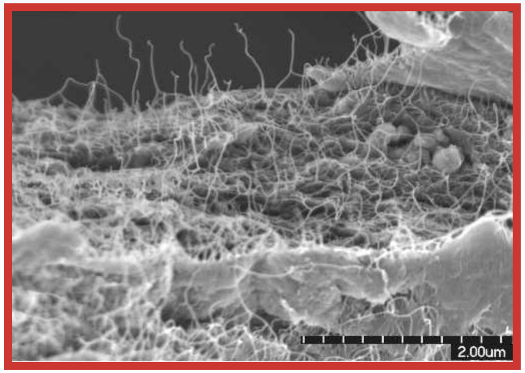
Agglomeration of carbon nanotubes in polymer without any treatment



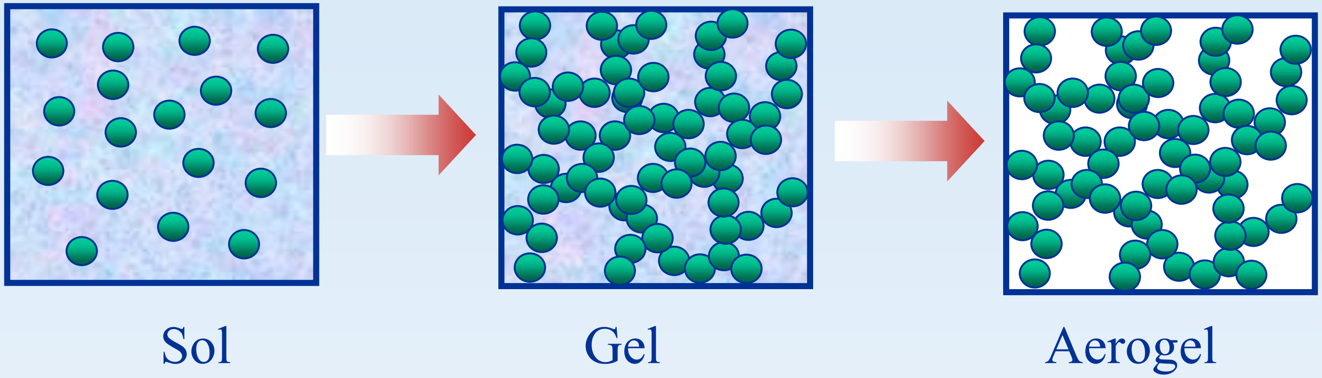
Functionalization of nanotubes



Uniform distribution of nanotubes

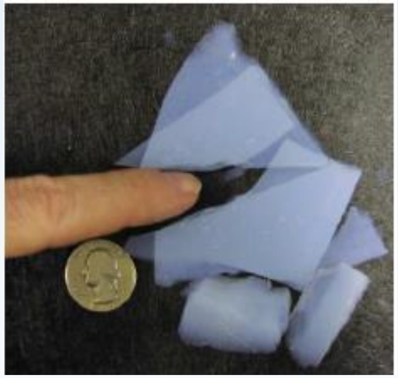


Aerogels



- Highly porous solids made by drying a wet gel without shrinking
- Pore sizes extremely small (typically 10-40 nm)—makes for very good insulation
- 2-4 times better insulator than fiberglass under ambient pressure, 10-15 times better in light vacuum

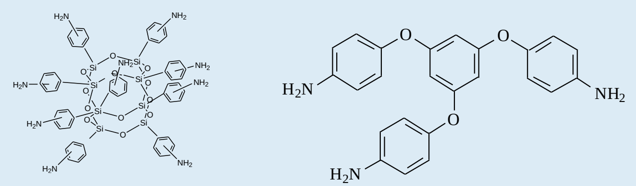
However, silica aerogels are extremely fragile…



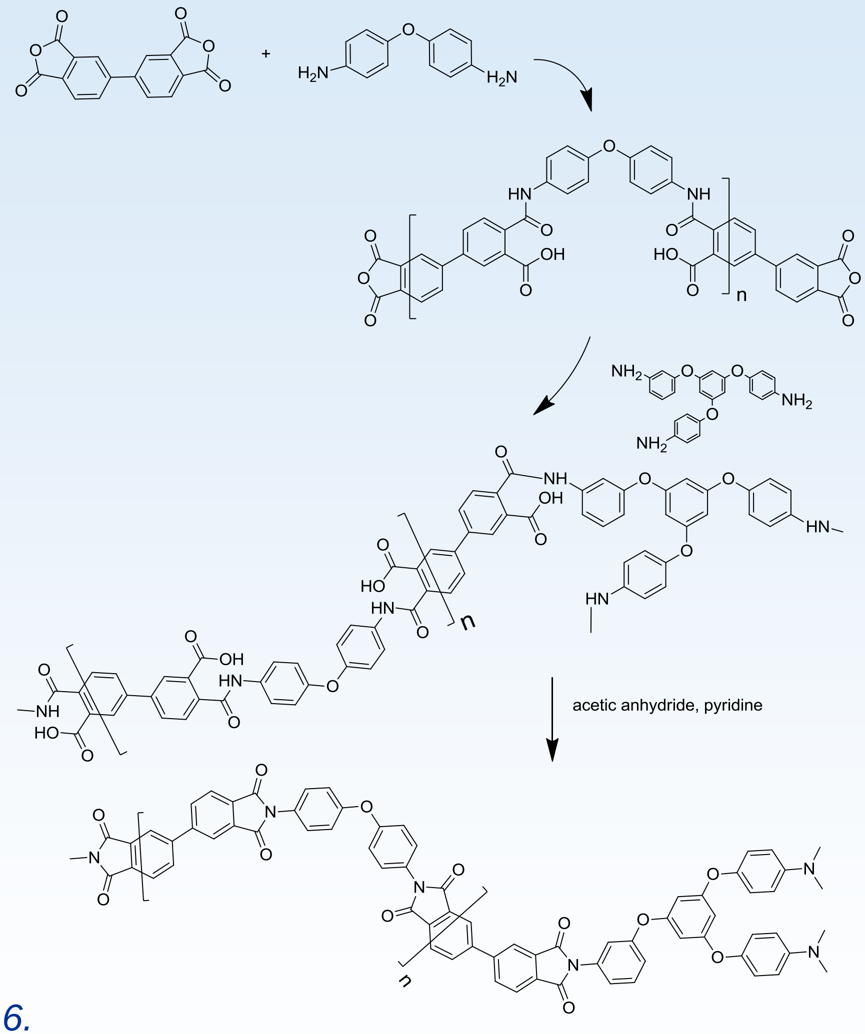
…and therefore limited to a few exotic NASA applications

Cosmic dust collector – Stardust Program

Development of Strong Polyimide aerogels



POSS TAB

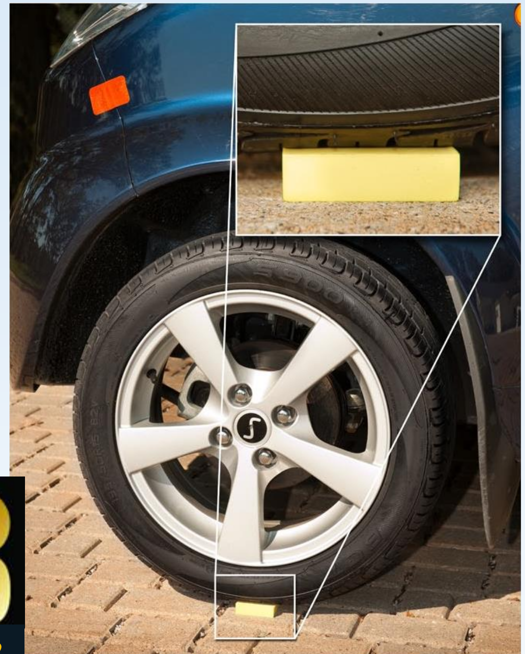


- Made by cross-linking polyimide oligomers to form gel network
- Aromatic triamine (TAB) or POSS decorated with eight aminophenyl groups
- Supercritical fluid extraction

Meador, US Patent 9,309,369, April 12, 2016.
Meador and Guo, US Patent 9,109,088, August 18, 2015.
Nguyen and Meador, US Patent 8,974,903, March 10, 2015.

Application of Polyimide (PI) Aerogel

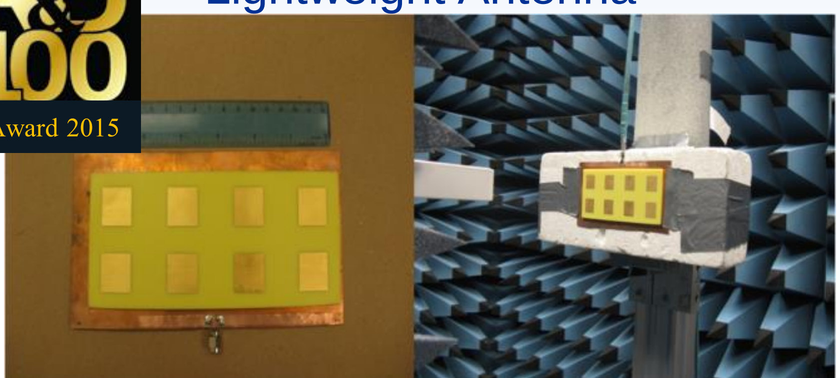
Polyimide (PI) aerogel easily supports the weight of a car



R&D 100 Award 2012

R&D 100 Award 2015

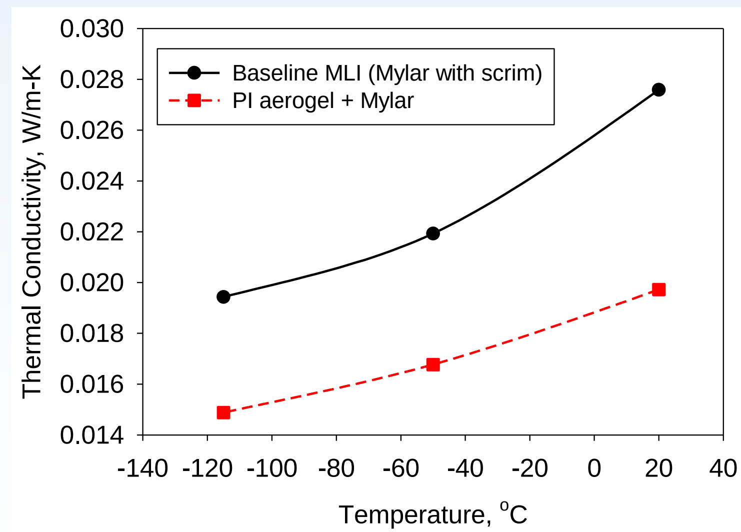
Lightweight Antenna



MLI incorporating aerogel in place of scrim reduces thermal conductivity by 23-37%

Baseline MLI (Mylar + scrim)

Pi aerogel + Mylar



MLI with and without aerogel tested under simulated Mars atmosphere (8 Torr Argon, -120 to 20 ^{o}C)

Chemical Synthesis of Graphene-Like Boron Nitride Nanosheets

Mixture:
hBN
Intercalate: $FeCl_3$
Activation agent: NaF

↓ 260 to 360 °C in nitrogen

$FeCl_3$ moves into hBN layers during heating (intercalation)
Intercalated hBN

↓ Room-temperature wet air (optional)

Moisture in air moves into hBN (adsorbed by hygroscopic $FeCl_3$ in hBN)

↓ Heating to 750 °C or higher

Evaporate water and evaporate/oxidize $FeCl_3$
Exfoliated hBN in Fe_2O_3

↓ 35 wt% HCl room temperature

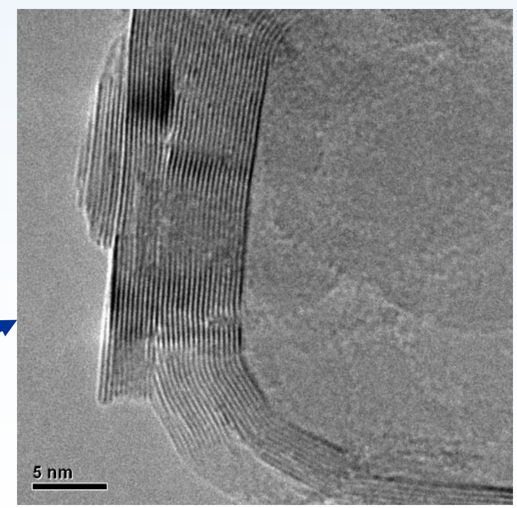
Dissolve NaCl and majority of all iron oxides

↓

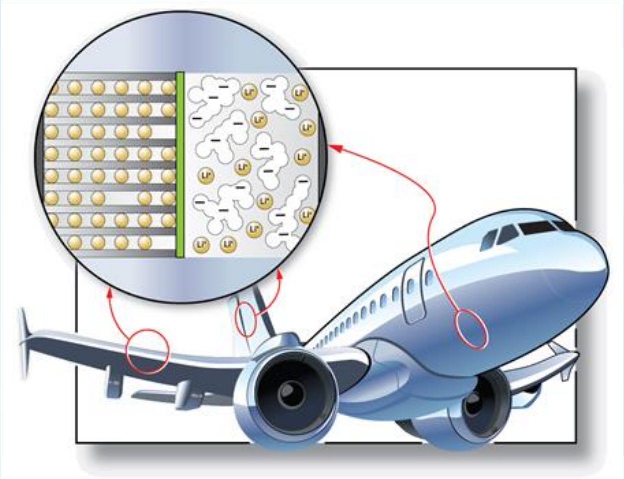
Pure exfoliated hBN

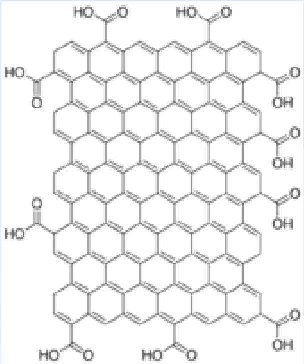
Hexagon boron nitride (hBN) nanosheet, analogous to graphene, has excellent mechanical, thermal, and electrical properties for incorporation in nanocomposites

hBN Nanosheet

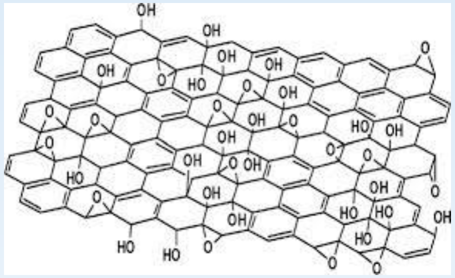


Multifunctional Nanomaterials with Load-Bearing and Energy Storage Capability

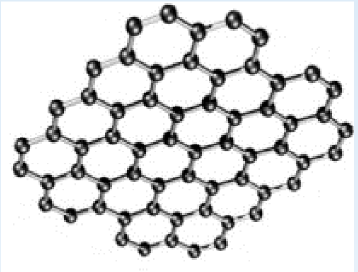




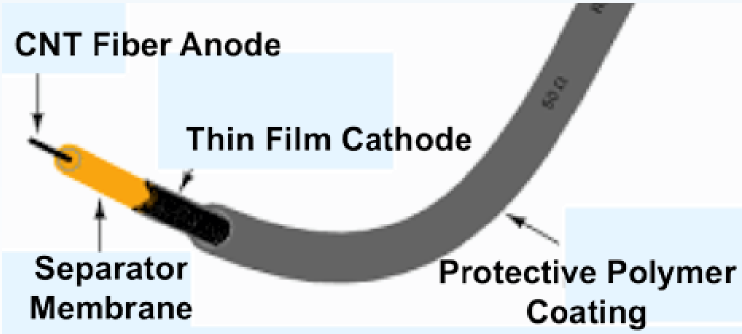
Graphene Oxide



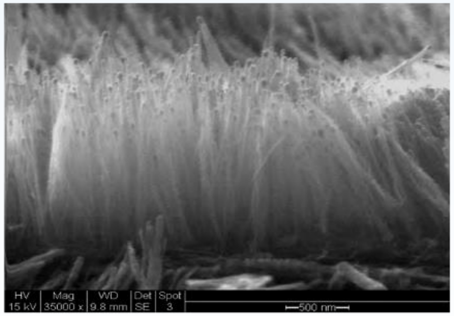
Functionalized Graphene



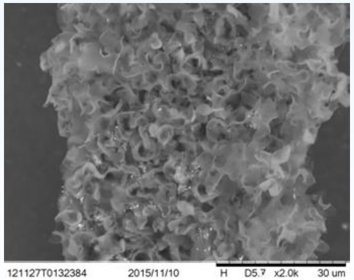
Reduced Graphene Oxide



Wire Electrode

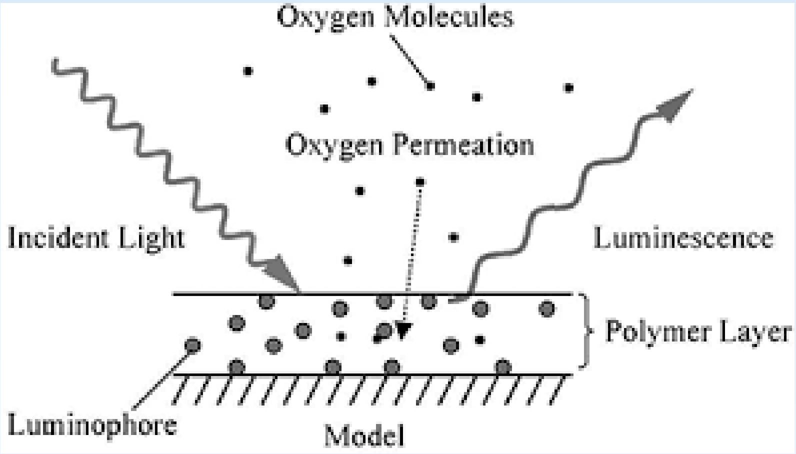


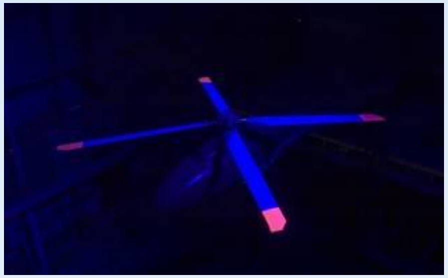
CNT Grown on CNT Sheet



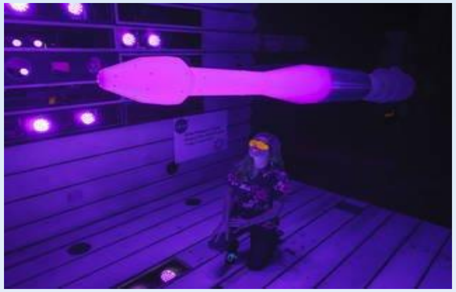
Graphene/CNT Hybrid Fiber

Pressure-Sensitive Paint



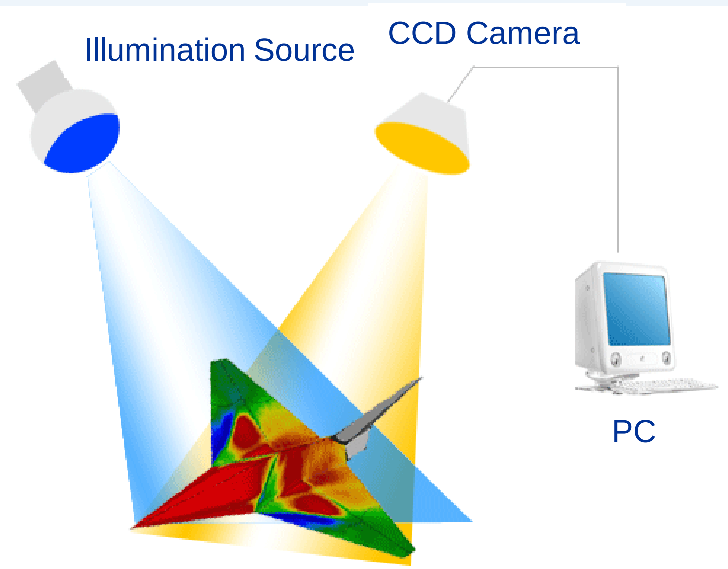


Pressure-sensitive paint covers the blade tips of a helicopter being tested in a wind tunnel at NASA's Langley Research Center



Pressure-sensitive paint for testing of generic launch vehicle model

- Optical method to measure pressure on aerodynamic surface
- Luminescent coating sprayed over surface

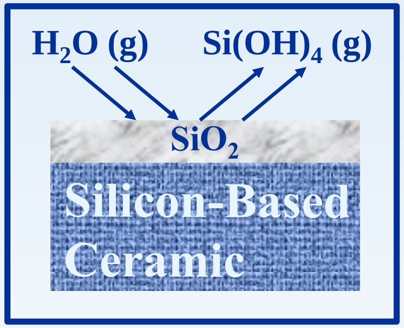


Environmental Degradation of Ceramic Matrix Composites (CMCs) in Gas Turbine Engine Environment

Silicon carbide fiber reinforced silicon carbide ceramic matrix composite (SiC/SiC CMC) is the next generation of gas turbine engine hot section material, as they offer significant increase in temperature capability with the benefit of higher thermal efficiency

SiC/SiC CMC

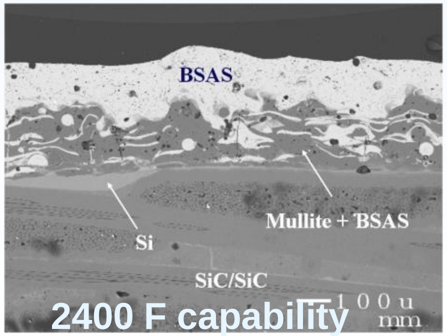
Reaction of CMC with moisture in turbine engine

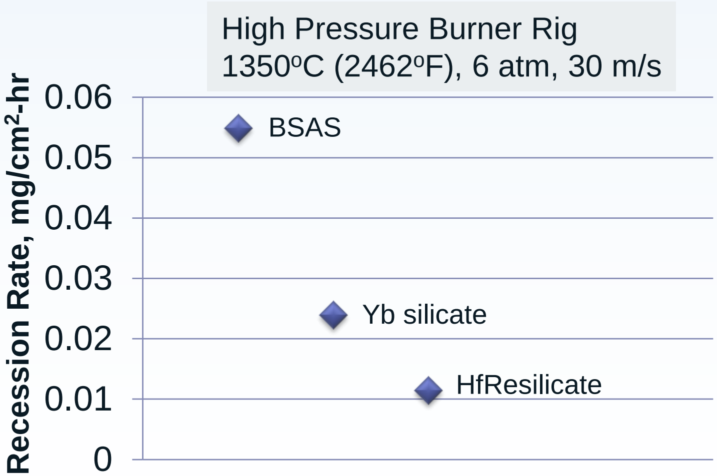


Identification of reaction products using unique Knudsen Effusion High Temperature Mass Spectrometry capability

First to identify $Si(OH)_4$ product for reaction of SiC with moisture

Barium Strontium Aluminum Silicate (BSAS) environmental barrier coating (EBC) – First Gen.





Complex rare-earth silicate coatings under development to increase temperature capability

New Durability Challenges with Increase in Temperature Capability of Gas Turbine Engines

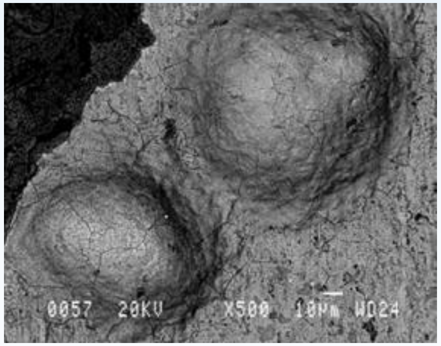
Aircraft engine ingests sand upon take-off

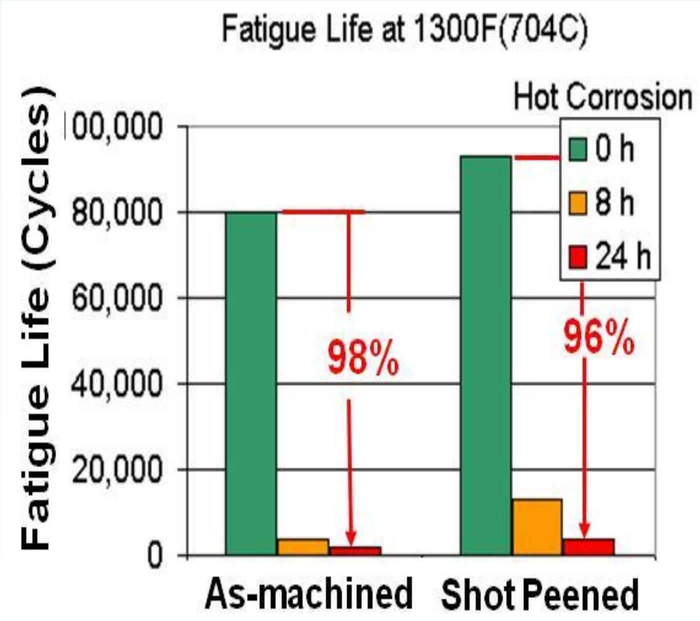
Dust storm in Phoenix, Arizona

Volcano eruption

Ingestion of dust and aerosol particles deposits molten substance on gas turbine engine hot section components – causing high temperature corrosion of engine components (recent problem with introduction of gas turbine engines with higher engine temperatures)

Pitting corrosion due to deposition of molten substance, reducing life by orders of magnitude

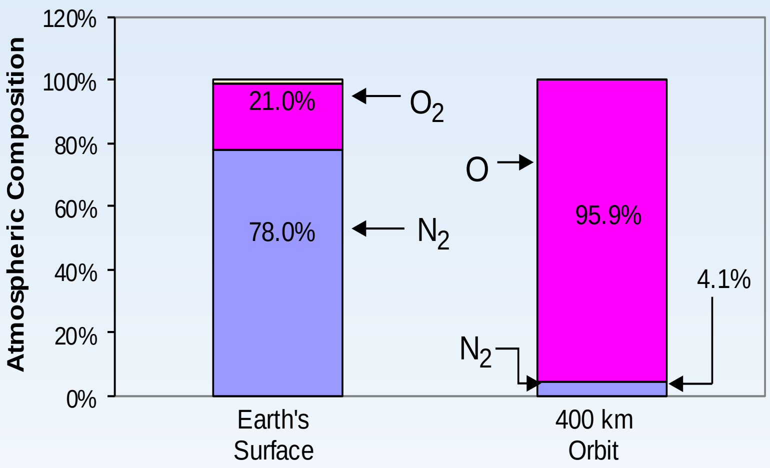




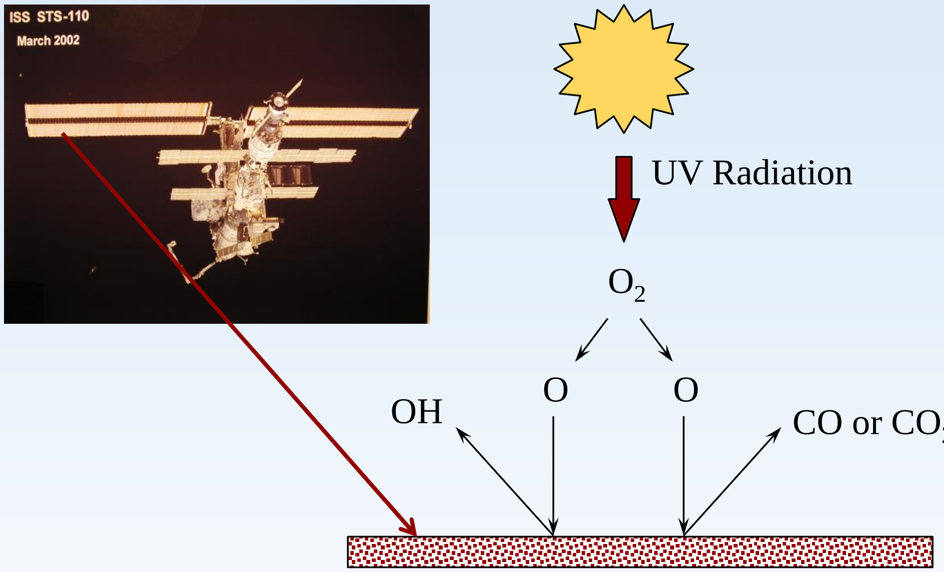
Understanding chemistry of deposits and the reaction mechanisms for materials, along with development of coatings to prevent corrosion are active areas of research

Material Degradation Caused By Space Environment

Atmospheric Composition

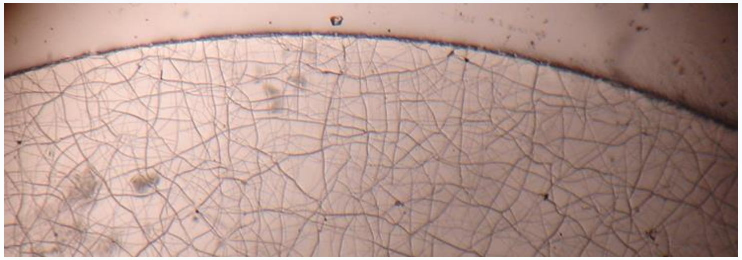


Atomic Oxygen Interaction with Organic Surfaces



Oxidative Cracking of Silicone, DC 93-500 Silicone Exposed to Oxygen on STS-46

Before Flight



After Flight

Summary

- New materials enabled by
  - New chemistries offering unique properties
  - Chemical processing techniques

- Durability of materials in harsh environments requires understanding and modeling of chemical interaction of materials with the environment