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 requirements for large structures

Low carbon and low emission aircraft

Lightweight and durable mechanical system/mechanisms

Long-term durability in harsh environments

Computational modeling across multiple length scales
Materials Research at GRC

High Temperature Materials
- Ceramic Matrix Composite
- Protective Coatings
- Hybrid Disk
- Thermal Protection Seal
- Hybrid Composite Gear
- Lattice Block
- Flexible Aerogel
- Nanotube Yarn
- Lightweight Power Transmission Cable
- Solid Oxide Fuel Cell Material
- Materials for High Power Density Electric Motors

Lightweight Materials
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Power System Materials
- Hybrid Composite Gear
- Lattice Block
- Flexible Aerogel
- Nanotube Yarn
- Lightweight Power Transmission Cable
- Solid Oxide Fuel Cell Material
- Materials for High Power Density Electric Motors

Mechanical System Materials
- High Efficiency Gear
- Shape Memory Alloy
- High Temperature Lubrication Coating
- Seal Materials

Computational Modeling
- Computational Modeling
- Lattice Block
- High Temperature SMA Chevron
- Pressure Sensor
- Luminescence Coating
- Energy Harvesting for Sensor

Sensor Materials
- Pressure Sensor
- Nox and CO Sensor
- Luminescence Coating
- Energy Harvesting for Sensor
- MoSi2 CrSi2 CoSi
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
- Fan case
- Vanes
- Fan blades

Polymer Composite Aircraft Structure

Electric Components in Electric Aircraft
- Sensors
- Thermal Insulation

Polymer Composite Space Structures
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

Nanotube Fiber
Crosslinking
Covalent Crosslinks
Improvements in Strength of CNT Sheets Through Combination of Post-Processing Treatments

Tensile Strength Comparison for Various Treatments of Carbon Nanotube Sheet (lot 5333)

- Hydroxyl functional material prepared by reaction with azido ethanol (nitrene route); E Beam treatment, 90 min exposure, $2.2 \times 10^{17}$ e$^-$/cm$^2$ total fluence
Toughness Improvement of Polymer Composites Through Incorporation of Nanofabric

Thermoplastic Polyurethane Veil

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
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

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

Application of Polyimide (PI) Aerogel

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

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

Baseline MLI (Mylar + scrim) compared to PI aerogel + Mylar.

MLI with and without aerogel tested under simulated Mars atmosphere (8 Torr Argon, -120 to 20 °C).

Lightweight Antenna Award 2012, 2015.

Glenn Research Center at Lewis Field
Hexagon boron nitride (hBN) nanosheet, analogous to graphene, has excellent mechanical, thermal, and electrical properties for incorporation in nanocomposites.

**Chemical Synthesis of Graphene-Like Boron Nitride Nanosheets**

**Mixture:**
- hBN
- Intercalate: FeCl$_3$
- Activation agent: NaF

**Procedure:**
- **Intercalated hBN**
  - FeCl$_3$ moves into hBN layers during heating (intercalation)
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  - 260 to 360 °C in nitrogen
- **Moisture in air moves into hBN (adsorbed by hygroscopic FeCl$_3$ in hBN)**
  - Room-temperature wet air (optional)
  - Heating to 750 °C or higher
- **Evaporate water and evaporate/oxidize FeCl$_3$**
  - Exfoliated hBN in Fe$_2$O$_3$
  - 35 wt% HCl
- **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.
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

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

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
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

\[
\text{H}_2\text{O} (g) \quad \text{Si(OH)}_4 (g) \quad \text{SiO}_2
\]

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

First to identify \(\text{Si(OH)}_4\) 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

<table>
<thead>
<tr>
<th>Recession Rate, mg/cm(^2)-hr</th>
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<tbody>
<tr>
<td><strong>BSAS</strong></td>
</tr>
<tr>
<td><strong>Yb silicate</strong></td>
</tr>
<tr>
<td><strong>HfResilicate</strong></td>
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High Pressure Burner Rig

1350°C (2462°F), 6 atm, 30 m/s
New Durability Challenges with Increase in Temperature Capability of Gas Turbine Engines

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

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