Graphene Polymer Nanocomposites

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Thermal, Mechanical Properties, and Fracture Toughness of Surface Modified Graphene Epoxy Nanocomposites

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Polymer Nano-Composites for Aerospace Applications

Multi-Functional Materials

Reinforcements, Mechanical strength in a wide temperature range - Barrier - Toughness

- Graphene
- Layered Silicates
- Carbon NT
- Expanded Graphite
- Carbon nanofibers
- Magnetic nanoparticles
- Organometallic physical crosslink

Conductive Polymers

DC & AC Electrical - Permittivity - Stiffness / Ductility

Smart Adaptive Materials

Actuation – Thermal, Magnetic, Electrical

- Morphing fan casing
- Blended wing body inlet
- Flex. packaging
- Space deployable structures

Sensors

Static discharge
Lightening strike
Actuators

A two-seat F106B jet made 1,496 thunderstorm penetrations and got struck by lightning 714 times during NASA’s eight-year Storm Hazards Research Program. Credit: NASA

Figure 2. SMP Composite Truss in Packed and Deployed Configurations

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Graphite and Graphene

Graphite:
- Advantages: Naturally abundant material, Low cost

Graphene:
- Mechanical peeling
- CVD
- Acid intercalation, thermal shock, sonication
- Acid intercalation followed by high pressure, high temperature treatments

Graphene:
- In-plane stiffness of 1,060 GPa
- Resistivity in the range of 50 μΩ cm
- 98.7% transmission normal to the incident beam for the first layer, 2.3% reduction for the next layers in vacuum
- Thermal conductivity: ~ 3000 W/mK
- Field effect mobility of 200 000 cm²/Vs


Polymer nanocomposites, optoelectronic applications; transparent conductors, field emission displays, supercapacitors, devices, emissive displays, micromechanical sensors.
Graphene Surface and Interface

**Tailored Interface**
- Compatibility with the polymer matrix
- Improving dispersion
- Load/stress transfer
- Electron transfer
- Thermal energy transport

**Surface Characteristics:**
- SP² hybridization for electron transport
  - van der Waal Interaction (aromatic structures)
- Combination of sp³ and sp² hybridization
  - Covalent bonding; -OH, -COOH, -phenolic-OH, -epoxide

**Covalent bonding**

Grafting to

Grafting from
Epoxy Graphene Nanocomposites-Reinforcement

Objectives:
• To determine the effects of graphene addition and surface modification on the thermal and dynamic modulus, fracture toughness of the low content graphene nanocomposites.

Epoxy: Epon 826
Chemical and heat resistance
Good to excellent mechanical properties
Low viscosity resin
Transparent
Excellent adhesion

Jeffamine D230: a polyetheramine, (an amine terminated PPG)
MW 230, X ~ 2.5

Dispersion via sonication

Reinforcement, toughness and thermal properties

Polymer+

• Solution mixing
• Sonication
• High shear mixing

Epoxy

- Dynamic mechanical analyzer, modulus, $T_g$
- Fracture toughness
- TGA
- Morphology; electron microscopy
Epoxy Graphene Nanocomposites - Surface Modifications

Reduced graphene

O- graphene

Reduced graphene
sp² hybridized

Highly oxygenated graphene,
sp², and sp³

Amino propyl polydimethyl siloxane
graphene, sp², and sp³

2500 – 27000 g/mol

Weight, %

14 wt%

320 °C

86%

Intensity, counts

C1s

OKLL

O1s

Cl2p

S2p

Temperature, °C

Absorbance

Wave numbers, cm⁻¹
XPS, O- Graphene Surface

XPS

A range of carbon oxygen moieties with 7% atomic oxygen (high resolution survey scans).

\[ \text{O1s binding energy: 532.73 eV} \]

\[ \text{C=O, C-O, O-C-O} \]

\[ \text{C1s: 285.07, 286.78, 289.2, 291.48, 294.19 eV} \]

Bonding energies: ester, carboxylic, ether carbon, hydroxyl carbon, phenolic hydroxyl, carbonate, ..

O1s binding energy: 532.3 eV
ketone, ester, or acetate


XPS – Surface Modified

Atomic percentage, %

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<th>C1s</th>
<th>O1s</th>
<th>Si2p</th>
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Binding Energy, eV

Intensity, a.u.

Epoxy Graphene Nanocomposites

Glass Transition Temperature

Graphene loading
0.05 - 0.5 wt%
Graphene loading 0.05 - 0.5 wt%
**Mode I Fracture Toughness**

The fracture toughness improved with low graphene content, where further addition of graphene resulted in $K_{IC}$ deterioration.

$$K_{IC} = \frac{P_{\text{max}}}{B^{\frac{1}{2}}Wf(x)}$$

$$f(x) = 6x^{1/2} \left[ \frac{1.99 - x(1 - x)(2.15 - 3.93x + 2.7x^2)}{(1 + 2x)(1 - x)^{3/2}} \right]$$
Epoxy Graphene Nanocomposites
Thermal Stability

Graphene, wt% vs. $T_d^o$ °C

O-graphene,
Reduced graphene,
PDMS-graphene,
Neat Epoxy
Good dispersion was obtained in all nanocomposites.
Fractured, O₂ plasma treated surface of PDMS-Graphene epoxy nanocomposites

0.5 wt% PDMS-graphene Nanocomposites
Concluding Remarks

• Low graphene content (0.05-0.5 wt%) graphene epoxy nanocomposites using reduced graphene, O-graphene, and surface modified graphene were prepared by solution mixing.

• All nanocomposites exhibited improvements in glass transition temperature, modulus, thermal stability, and fracture toughness.

• TEM studies showed good dispersion of graphene in the epoxy resin matrix.

• SEM micrographs indicated crack generation and energy dissipative phenomena in the graphene nanocomposites compared to neat epoxy.
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GRC Lead for the agency nanotechnology

- NRA – Aeronautics
  - NASA inspire web site

- NASA Graduate Student Researchers Program (GSRP)
  - [http://fellowships.hq.nasa.gov/gsrp/nav/](http://fellowships.hq.nasa.gov/gsrp/nav/)

- NASA Undergraduate Student Research Program (USRP)
  - [http://usrp.usra.edu/](http://usrp.usra.edu/)

- NASA Experimental Program to Simulate Competitive Research (EPSCoR)

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