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

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

Smart Adaptive Materials
Actuation– Thermal, Magnetic, Electrical

- Sensors
  Static discharge
  Lightening strike
  Actuators

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

Figure 2. SMP Composite Truss in Packed and Deployed Configurations
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

Absence of a sharp peak

D band defects

G band

E₂g

2942.5

3.48 Å


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:
- \( \text{SP}^2 \) hybridization for electron transport
  - van der Waal Interaction (aromatic structures)
- Combination of \( \text{sp}^3 \) and \( \text{sp}^2 \) hybridization
  - Covalent bonding; -OH, -COOH, -phenolic-OH, -epoxide

Covalent bonding
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

Durability - long-term
High-temperature service
Brittleness

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

Dispersion via sonication

Reinforcement, toughness and thermal properties

Epoxy

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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

Reduced graphene

Highly oxygenated graphene

Amino propyl polydimethyl siloxane graphene

Graphene

Reduced graphene

Highly oxygenated graphene

Amino propyl polydimethyl siloxane graphene

Graphene
XPS, O- Graphene Surface

XPS

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

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
O1s binding energy: 533.73 eV
adsorbed CO


XPS – Surface Modified

Atomic percentage, %

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<th>C1s</th>
<th>O1s</th>
<th>Si2p</th>
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<tr>
<td>Value</td>
<td>79.1</td>
<td>14</td>
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![Graph showing XPS spectra and atomic percentage]

Epoxy Graphene Nanocomposites

Glass Transition Temperature

Graphene loading
0.05 - 0.5 wt%

Graphene epoxy nanocomposites, wt%
Graphene loading 0.05 - 0.5 wt%
Epoxy Graphene Nanocomposites
Fracture Toughness

Mode I Fracture Toughness

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

$$K_{IC} = \frac{P_{max}}{B^{1/2}W} f(x)$$

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

Graphene, wt% vs. $T_d$, °C

- Neat Epoxy
- O-graphene,
- Reduced graphene,
- PDMS-graphene,
Epoxy Graphene Nanocomposites - Dispersion

Good dispersion was obtained in all nanocomposites.

Reduced graphene in epoxy

O-graphene in epoxy

PDMS modified graphene in epoxy 0.05 wt%
SEM

Fractured, $O_2$ 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/

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

- NASA Experimental Program to Simulate Competitive Research (EPSC)

- NASA Glenn Faculty Fellowship Program (NGFFP)
  - http://nbpo.grc.nasa.gov/university-affairs/ngffp/

- LERCIP Higher Education (College) – Undergraduate program

- Space Grant Consortium