Tailoring Polymer Composites for Space: Realizing Electrically Conductive Polymer Composites Through Reinforcement with Chemically-Modified Reduced Graphene Oxide

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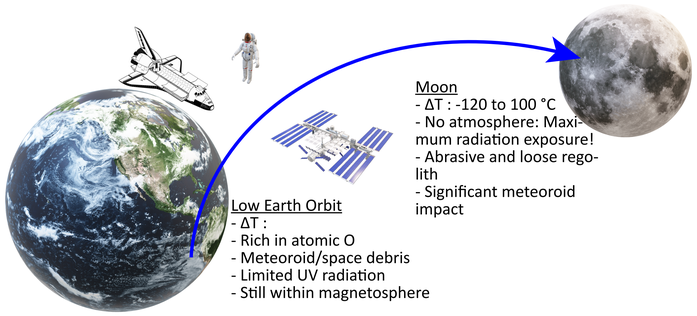
1. Understanding Risks in Space



1.1 Micrometeoroid Impact

- Small (nano or micron) scale meteoroids moving at high speeds
- Can occur naturall or from debris during take-off and landing operations
- Difficult to predict due to small size

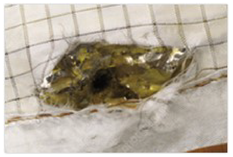


Fig. 1: Micrometeoroid impact on the Zarya module of the ISS. Photo Credits: NASA, taken June 6, 2007.

1.2 Radiation Exposure

- UV exposure in the presence of atomic O is devastating to polymers
- Solar Particle Events and Neutrons can initiate radical generation.
- Galactic Cosmic Rays are extremely difficult to stop but don't occur often

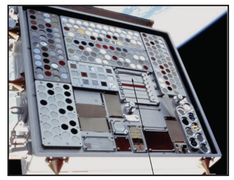


Fig. 2: Panel from previous ISS missions that contains various materials exposed to LEO conditions. Fickernor, 2017.

1.3 Static Charging

- Static charging occurs readily on insulating bodies due to the lack of moisture to dissipate charges as on Earth.
- Most polymers are insulators and require expensive coatings to be shielded against static charge generation.
- If left unprotected, short circuits can occur that lead to equipment failure.

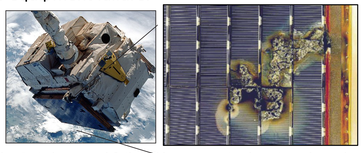


Fig. 3: Solar panel failure due to static charging aboard Eureca STS-57

1.4 Regolith Abrasion

- Top layer of "rocky" material on the Moon or Mars
- Electrostatically charged and stick to surfaces
- Very abrasive on bearings and joints
- Active systems to remove regolith dust have been designed dating back to the Apollo era.

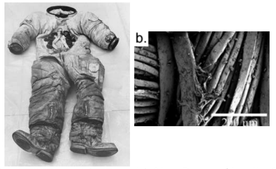


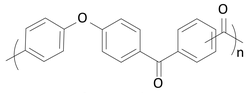
Fig. 4: Apollo-era astronaught Alan Bean's (Apollo 12) AL7 space suit after mission completion. Photo Credits: NASA

2. Polymers as Space Materials

Polymers are compelling materials for space applications due to their low density (light weight) and many properties that are uniquely suited to the space enviornment:

- Range of mechanical and functional properties
- Many are H rich and are therefore strong radiation attenuators
- Stable nuclei due to low Z elemental composition
- Most are electronically insulating and therefore statically charge

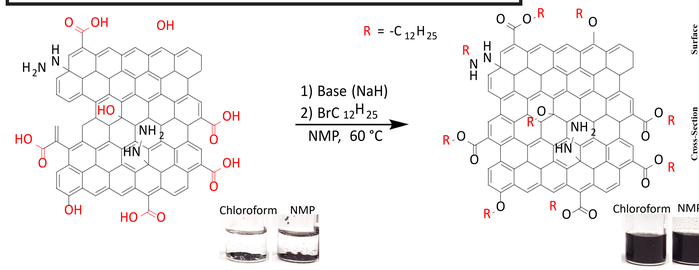
Polyethylene (PE)



PEKK/PEEK (OxPEKK)

Fig. 5: HDPE Insulation around crew quarters aboard the ISS as shielding against radiation (left) and current 3D printer on ISS used to fabricate tools and components from thermoplastics.

3. Compatibilizing Reduced Graphene Oxide



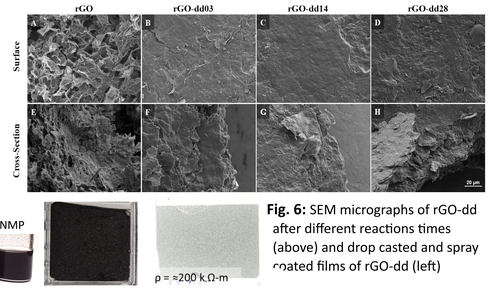
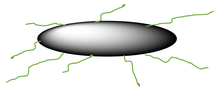


Fig. 6: SEM micrographs of rGO-dd after different reactions times (above) and drop casted and spray coated films of rGO-dd (left)

Reduced graphene oxides (rGO) are a type of graphene obtained from graphite flake via chemical exfoliaiton, oxidation, and reduction. While more processible than many graphene structures, rGO still suffers from a general lack of solubility and miscibility with most solvents and polymers. The development of rGO-dd solves many of these issues and enables the fabrication of numerous types of composite samples.

4. rGO-dd Laminate Layer Formation

Step 1: Disperse rGO-dd into working solvent:



Step 2: Cast rGO-dd onto mold or thermoplastic

Step 3: Affix plastic into mold

Step 4: Cast rGO-dd onto mold or thermoplastic

Fig. 7: Fabrication procedure for rGO-dd lamination where rGO-dd is shown in green and the matrix polymer is shown in blue.

5. Simulated GCR and SPE Exposure

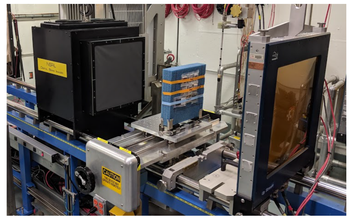


Fig. 8: Sample exposure hall at the NSRL. Samples are taped onto a foam board for support and placed before a detector to monitor dose.

- Radiation treatments simulating a round trip expedition to Mars were performed at the NASA Space Radiation laboratory (NSRL), which is located on the campus of Brookhaven National Laboratory. (left image)
- Galactic Cosmic Ray Simulation:
  - P1000, Si600, He250, O350, Fe600, and P250
  - Acute and low dose rates
- Solar particle event
  - Proton energies: 50-150 MeV
- Samples exhibited no observable signs of degradation (right) and retained sheet resistances equivalentto the control.

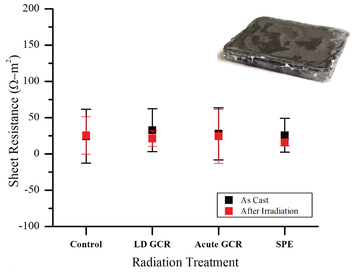


Fig. 9: Sheet resistances for laminated rGO-dd14 before and after exposure to low and high dose galactic cosmic ray (GCR), and solar particle event (SPE)

6. Resistive Heating Performance

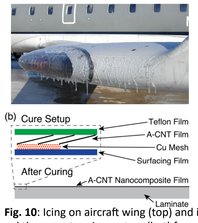


Fig. 10: Icing on aircraft wing (top) and internal thermoset curing system (bot) from App. Mat. & Inter., 2015.

- Means of controlling surface temperature by applying a voltage.
- Terrestrial applications include de-icing in commercial and military aircraft, curing thermoset resins without autoclave
- Preliminary trials using rGO-dd laminates as resistive heating elements.
  - Sample Area: 75 mm x 150 mm
  - PEEK & HDPE Matrix Polymers
  - Max Temp: 82 °C (at 20 V)

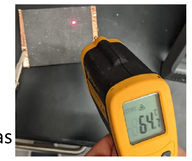


Fig. 11: IR thermometer measurement of rGO-dd laminated poly(ether ether ketone) in resistive heating trials.

7. Advanced Composite Design

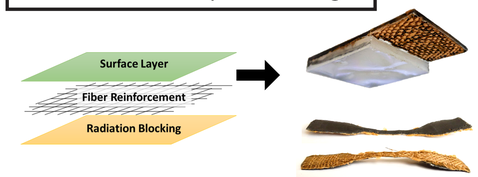
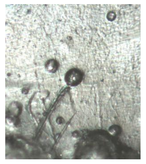


Fig. 12: Conceptual diagram (left) and prototype samples (right) of a fiber-reinforced multi layer composite that is laminated with rGO-dd. The underlying fibers and thermoplastic can be chosen to meet the needs for different space applications.

8. Future Work

8.1 Simulated Micrometeoroid



- Do rGO-dd coatings provide any protectivebenefits to underlying polymer materials?
- Are the mechanical and/or electrical properties affected by the micrometeoroid impact events?
- Internal REVEALS collaboration with Ian Dowding (GT)

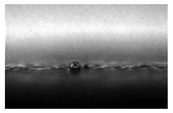


Fig. 13: Image of a 14 μm particle imbedded into polymer, crater formed (top) and 25 μm particle resting on polymer after colliding with insufficient energy to penetrate the polymer surface (left).

8.2 Active Dust Mitigation

- Use electric charge to repel charged regolith particles from insulating surfaces.
- Electric curtain developed at NASA Kennedy (1967)

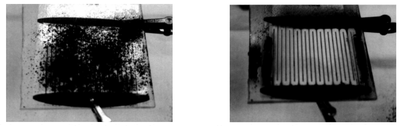


Fig. 14: Images of charged regolith dust distribution over a patterned conductive surface before and after applying electric curtain effect across panel. Dust is electrostaically thrown from surface. rGO-dd laminates could be used in
1) Space Environmental Effects on Dust Mitigation Technology: A MISSE-X Experiment , 2012
2) Lunar Dust Degradation Effects and Removal/prevention Concepts. (1967).

8.3 Determine rGO-dd Vulnerabilities

- Overarching Goal: determine if rGO-dd can withstand harsh environments encountered in space and to what extent are underlying materials protected from these elements when laminated.
- Focus of International Space Station research proposal (submitted May 2020) in which samples will be strategically exposed to various combinations of: atomic oxygen, UV light, micrometeoroids, ionizing radiation
- Pending proposal outcome, alternative ground-based experiments are being planned.

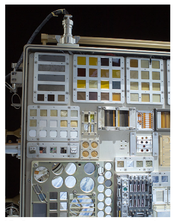


Fig. 13: Sample exposure panel typical of MISSEE missions aboard the ISSRL. Each window exposes a sample to LEO conditions. The panel is installed using robotic arms piloted by astronauts.

9. Acknowledgements

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For questions or additonal information please contact Zach Seibers at zachseibers@gmail.com.