Electron Beam Irradiated Intercalated CNT Yarns For Aerospace Applications

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Background and Goals

- Previous data suggested that yarns irradiated by an e-beam showed an improvement in tensile properties.
- CNT fibers and yarns could potentially be used for multifunctional devices - electrical conductor, data line as well as a tendon for movement.
- Electrical conductivity could be doubled with intercalation - **100 kS/cm** is needed to equal copper’s specific conductivity.
- Goal: To determine the effects of intercalation and irradiation on the electrical and mechanical properties of CNT yarns.
CNT Fibers

• Nanocomp Technologies NB87 and NB106

• “(Nanocomp Technology Inc.) production systems generate a "cotton candy" or "stocking-like" flow of millimeter-length CNTs that can be translated into multiple formats, each of which possess a different mix of strength and conductivity”, including lightweight wires and yarns

http://www.nanocomptech.com/conductors-and-yarns
Electron Beam

- NEOBeam is an electron beam accelerator owned by Mercury PlasKcs, Inc. (Middlefield OH)
- It is used to cross-link polymeric materials
- 2 MV electron beam (capable of 5 MV)
- The electrons break C-H bonds and facilitate C-C bonds

http://www.mercuryplastics.com/neo-beam
Intercalation of CNT yarns

- Treat CNT fibers in glass reaction vessel with a combination of Bromine, Chlorine and Iodine
- Halogen concentrations and temperatures were held constant for the reactions in the test matrix
Test Equipment

Conductivity – 4-Point Probe Resistance measurement

Tensile Testing – Instrumet Corporation
RENEW 1125

Raman Spectroscopy - Renishaw System 2000 Microscope with Ar+ ion laser at 514 nm

SEM/EDS – Hitachi S-3500N / Thermo Scientific UltraDry 4455D
Results – Conductivity With Time – NB87

- As-Received
- Int
- EB 20 min
- EB 40 min
- Int+EB 20 min
- Int+EB 40 min
- EB 20 min+Int
- EB 40 min+Int

Conductivity (kS/cm) vs. Time After Last Processing Step (days)
Results – Conductivity With Time – NB106

![Graph showing Conductivity vs. Time for different processing steps: As-Received, Int, EB, Int+EB, EB+Int. The graph includes data points for time intervals of 20 and 40 minutes.]
Results – Conductivity (kS/cm) NB87 (solid) and NB106 (striped)
Results – Tensile Test – NB87 Int + E-beam 40 min

4 Samples Tested
Results – Normalized Strength (N/tex)
NB87 (solid) and NB106 (stripes)
Results - Raman Spectroscopy

NB87 As-Received

NB87 E-beam 40 min

NB106 As-Received

NB106 E-beam 20 min
# Results – Raman D/G Ratios

<table>
<thead>
<tr>
<th>Fiber</th>
<th>As-Received</th>
<th>Int</th>
<th>EB 20 min</th>
<th>EB 40 min</th>
<th>Int + EB 20 min</th>
<th>Int + EB 40 min</th>
<th>EB 20 min + Int</th>
<th>EB 40 min + Int</th>
</tr>
</thead>
<tbody>
<tr>
<td>NB87</td>
<td>0.12</td>
<td>0.28</td>
<td>0.09</td>
<td>0.27</td>
<td>0.22</td>
<td>0.07</td>
<td>0.29</td>
<td>0.23</td>
</tr>
<tr>
<td>NB106</td>
<td>0.17</td>
<td>N/A</td>
<td>0.32</td>
<td>0.23</td>
<td>0.21</td>
<td>0.09</td>
<td>0.24</td>
<td>0.28</td>
</tr>
</tbody>
</table>
Results – SEM
NB87

As-Received

Int + E-beam 20 min
Results – SEM
NB106

As-Received

Int + E-beam 20 min
Results – EDS – NB87

E-beam exposes the chlorine which is used in the manufacturing process
Intercalation halogens appear and are reduced after E-beam
Conclusions

• Overall, for CNT electrical wires the NB106 performed better than the NB87 fibers in both conductivity and tensile properties.

• Mechanical strength of these particular fibers is not increased with the additional step of the e-beam beyond statistical error, but could help if intercalation is done in some cases.

• Conductivity decreases with time in general for these samples:
  • NB87 conductivity almost doubles with intercalation, it also shows an increase for any of the other processing steps.
  • NB106 conductivity approximately doubles with intercalation, intercalation before and after e-beam also shows an increase in conductivity, e-beam alone shows a decrease in conductivity.
Conclusions

- Raman showed some inconsistent results and should be repeated on a different Raman for verification.
- SEM generally showed some visual smoothing of NB87 surfaces after processing while the NB106 samples all appeared very similar.
- EDS showed consistently that the e-beam removed the halogenated materials unless intercalation took place after the e-beam.
Future Work

- Increase the conductivity of the wires through changes in reaction time, concentration and temperature
- In-situ resistance measurements during the reaction process to determine optimum conditions for intercalation
- Coat the intercalated fibers to slow the diffusion of halogens out of the fibers
- Stability of the fibers in other environments such as humidity and changing temperature
- Re-run test matrix samples on another Raman unit
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