EPOXY MEDIATED ALIGNMENT OF SINGLE WALL CARBON NANOTUBES UNDER HIGH MAGNETIC FIELDS

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Outline

- Carbon Nanotubes
- Reorientation of Carbon nanotubes and Polymers
- Experimental work:
  - Magnetic field-induced alignment of a bulk epoxy-nanotube samples
  - Results for alignment process (ESEM), atomic force microscopy (AFM) and wide angle x-ray diffraction (WAXD).
- Conclusions
Carbon Nanotubes

- Carbon nanotubes are near ideal whiskers consisting of folded-graphene layers with cylindrical hexagonal lattice structure
- Single walled: 0.4-1 nm diameter
- Multi-walled: 1.2-10 nm diameter
- Length: nm-mm
Chemical Vapor Deposition for in-Field Processing

Furnace

In-field & 0-field Processing (1200°C)

Thin film Nano-tubes...
Prototype
For Nano-tube CVD Production
Carbon Nanotubes Attractions

- High Young’s modulus (~1.2 TPa)
- High fracture strains (10-30%)
- Flexibility
- Low density
- Large aspect ratio
- Thermally stable up to 2800 °C in vacuum
- Thermal conductivity about twice as high as diamond
- Electric current-carrying capacity 1000 times higher than copper wires
Aligned Nanotubes

Well-aligned carbon nanotubes have been synthesized through:


When introduced to polymeric matrix, carbon nanotubes disperse randomly, losing their orientations. Hence, the reorientation process should take into consideration the rearrangement of the polymeric matrix.
Polymer Orientation In Magnet Fields

- Polymeric materials interact with magnetic field through the diamagnetic anisotropy of the constituent chemical units.

- The energy that the chemical unit gains through the interaction with magnetic field is dependent on the orientation of the unit relative to the magnetic field.

- There will be a tendency for polymer molecules to align with their chain axes parallel to a magnetic field specially when the randomizing influence of thermal energy is reduced as a consequence of the molecules being orientationally ordered within a mesophase.

- The tendency of a unit to align is suppressed by the thermal agitation if the energy reduction is insufficient compared to the thermal energy.
The sample was left to cure at 25 °C under 25 T field for 2 hrs to keep the viscosity as low as possible.

Then the furnace was heated up to 60 °C and the sample is left to cure under the magnet field for another 2 hours. After then the magnetic field was reduced to 0 Tesla, the samples were placed in another furnace at 60°C for another 2 hours to fully cure.

The experiment was repeated at 15 Tesla field with same magnetic processing and curing cycles as before.
ESEM micrographs for the morphology of the fracture surface for the magnetically processed epoxy samples at (a) 0 Tesla, (b) 15 Tesla and (c) 25 Tesla. The arrows represent the direction of the magnetic field.
ESEM image for the morphology of the fracture surface of SWCN-Epoxy composite processed at 0 Tesla Field. The fracture surface was captured at two magnifications: (a) 50 μm and (b) 10 μm.
ESEM image for the morphology of the fracture surface of SWCN-Epoxy composite. The arrow is the direction of the magnetic field. The darkest spots are clusters of the nanotubes.

The fracture surface was captured at two magnifications: (a) 50µm and (b) 10µm.
AFM microscopy for the SWCN-epoxy composite cured inside a 25 Tesla magnetic field.
Polished sections of the processed samples were obtained by sectioning parallel to the magnetic field direction.

The 2θ scan data were collected from 2θ = 1° to 30° in 0.01° steps for a period of 1 s per step.

A series of radial scans were obtained at various azimuthal angles (φ) by rotating the sample on its own plane between φ = 0° and φ = 360°. φ scans were performed in 0.1° steps for a period of 0.5 s per...
(A) 2θ diffraction along the azimuthal direction (θ=0°, normal to the magnetic field direction) for the 0, 15, and 25 Tesla cured epoxy samples.

(B) 2θ diffraction along the azimuthal direction (θ=90°, parallel to the magnetic field direction) for the 0, 15, and 25 Tesla cured epoxy samples. Samples don’t contain any SWCN.
Azimuthal (φ) scans of diffraction intensity for different magnetically-processed epoxy samples. All scans carried out for fixed 2θ = 19°.
Pole-figure of the (a) 0 T, (b) 15 T, and (c) 25 T magnetically processed epoxy samples.

The normalized raw pole densities plotted in units of time random distribution in which 1 corresponds to complete random orientation distribution.
Conclusions

- The microstructures of the polymer samples processed inside 15 and 25 Tesla fields were shown to have local orientation along the field's directions.

- The WAXD show a high degree of alignment when the azimuthal scan is parallel to the field direction $\phi=90^\circ$ and $2\theta=19^\circ$. The alignment was proportional to the strength of the magnetic field. The pole figures analysis confirmed this observation.

- The field-assisted reorientation in the epoxy samples used to utilize the alignment of SWCNs in the bulk samples based on the magnetic anisotropy between the composite two components.

- The carbon nanotubes are shown to be aligned at the nano-level, while the carbon nanotubes ropes did not align globally mainly because the length of the carbon nanotubes.