CARBON NANOTUBES - APPLICATIONS

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Carbon nanotubes

Carbone nanotubes (CNT) are graphene sheets rolled into tubular fibers.

Graphene is a single plate of Graphite crystalline structure consisting of hexagonal rings in which each carbon atom is covalently bonded to three other atoms in the plate.

Single wall carbon nanotubes (SWNT) are made of a single graphene sheet.
Multi-wall carbon nanotubes (MWNT) are made of multiple graphene sheets.

Typically nanotubes have a diameter of several nanometers (0.4-2nm of SWNT, 5-80nm of MWNT) and the length of tens of microns (1 nm = 1×10^{-3} μm = 1×10^{-9}m).

Carbon nanotubes are fabricated by the method of Chemical Vapor Deposition (CVD).

The most prominent properties of carbon nanotubes:

- ⊡ High stiffness (modulus of elasticity:: about 200,000 ksi (1400 GPa).
- ⊡ High tensile strength: up to 9,137 ksi (63 GPa).
- ⊡ High electrical conductivity. In theory carbon nanotubes may carry an electrical current with the density up to $2.5*10^{10}$ A/in^2 ($4*10^9$ A/cm^2).
- ⊡ High thermal conductivity: 24,267 in/(hr*ft²*ºF) (3500 W/(m*K)).

Carbon nanotubes in composite materials

Reinforcement of a polymer by dispersed carbon nanotubes enhances the material strength, stiffness (modulus of elsticity) and toughness.

Strength and stiffness are increased as a result of extremely high strength and modulus of elesticity of the incorporated carbon nanotubes.

Higher toughness is provided by an interaction between the polymer matrix and the reinforcing nanotubes. Such effect is a result of cracks deflection at the interface matrix-nanotube. When a crack

propagating through the matrix reaches nanotubes, the relatively weak bonding between the matrix and the fiber at their interface allows their relative sliding. The nanotubes bridge the crack and stop its propagation.

The main problem in fabrication of polymer composites reinforced with carbon nanotubes is agglomeration of the nanotubes and poor Homogenization of the material during its mixing.
The nanotubes tend to cluster together due to the great surface.

Examples of application of carbon nanotubes in polymer base composites:

- ⊡ Sporting equipment: tennis racquets, golf clubs, bicycles frames, hockey sticks, baseball bats. Carbon nanotubes reinforced polymer composites allows increasing the strength and improving dumping (vibration absorbtion) properties.
- ⊡ Wind turbine blades. Incorporation of carbon nanotubes in Carbon Fiber Reinforced Polymer Composites results in a significant increase (up to 35%) of strength and stiffness of the material.
- ⊡ Conductive polymer base materials. The composites are fabricated by addition of higly conductive carbon nanotubes into a non-conductive polymer matrix. The electrical conductivity of a polymer containing 10 wt.% of carbon nanotubes may reach 10,000 S/m. The resulting material is also stronger and tougher than the original polymer. The conductive polymers are used in automotive fuel supply lines for reducing the explosion risk by a dissipation of the electrostatic charge.

Carbon nanotubes in coatings

Polymer coatings containig dispersed carbon nanotubes are in fact polymer matrix composites deposited on a substrate in form of a thin layer.

The most promissing application of CNT of this type is conductive coatings.
0.5-1% of carbon nanotubes impart anti-static property to the polymer coating.
2-4% of CNT make the coating really conductive.

CNT containing conductive coatings are also used for anti-corrosion paints. The electrical conductivity of the coatings allows using Cathodic protection forcorrosion inhibition.

Carbon nanotubes in electronics

Exeptional electrical properties of carbon nanotubes (low electron scattering, high current carrying capacity, resistance to electromigration) has have generated a significant efforts in developing electronic devices based on CNT.

Examples of application of carbon nanotubes in electronics:

- Transparent films. CNT containing conductive transparent coatings are used in the applications where indium tin oxide or zinc oxide were commonly used: touch screen devices, photovoltaics, flexible displays.
- Thin Film Transistors (TFTs) made on CNT containing films.
- Gas sensors operating on the principle of measuring electrical resistance of a CNT containing film. Gas molecules absorbing by the nanotubes change the film resistance. The gas sensors of this type are capable to detect extremely low concentrations of gases (e.g. exploisive) in the atmosphere.
- Bio-sensors used for dection of small concentrations of bio-molecules such as DNAs and proteins.
- Flexible and stretchable electronic devices (e.g. flexible integrated circuits) using SWNT thin films on elastomeric substrates.

Carbon nanotubes in lithium ion batteries

Multi-wall carbon nanotubes (MWNT) are widely used in lithium batteries. Incorporation od nanotubes in graphite anodes and $LiCoO_2$ cathodes results in better electrical connectivity and higher mechanical properties of the batteries.

Carbon nanotubes in water treatment devices

Carbon nanotubes are used for fabrication fine water filters for drinking water purification.
Membranes made of aligned encapsulated carbon nanotubes possess very high permeability of liuids and gases and therefore. Therefore the water desalination by reverse osmosis utilizing such membranes is more cost effective than that with polycarbonate membranes.

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