Hyperion Catalysis

Materials Integrity Management Symposium
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Carbon Multiwall Nanotubes (CMWNT)

A High Performance Conductive Additive For Demanding Plastics Applications

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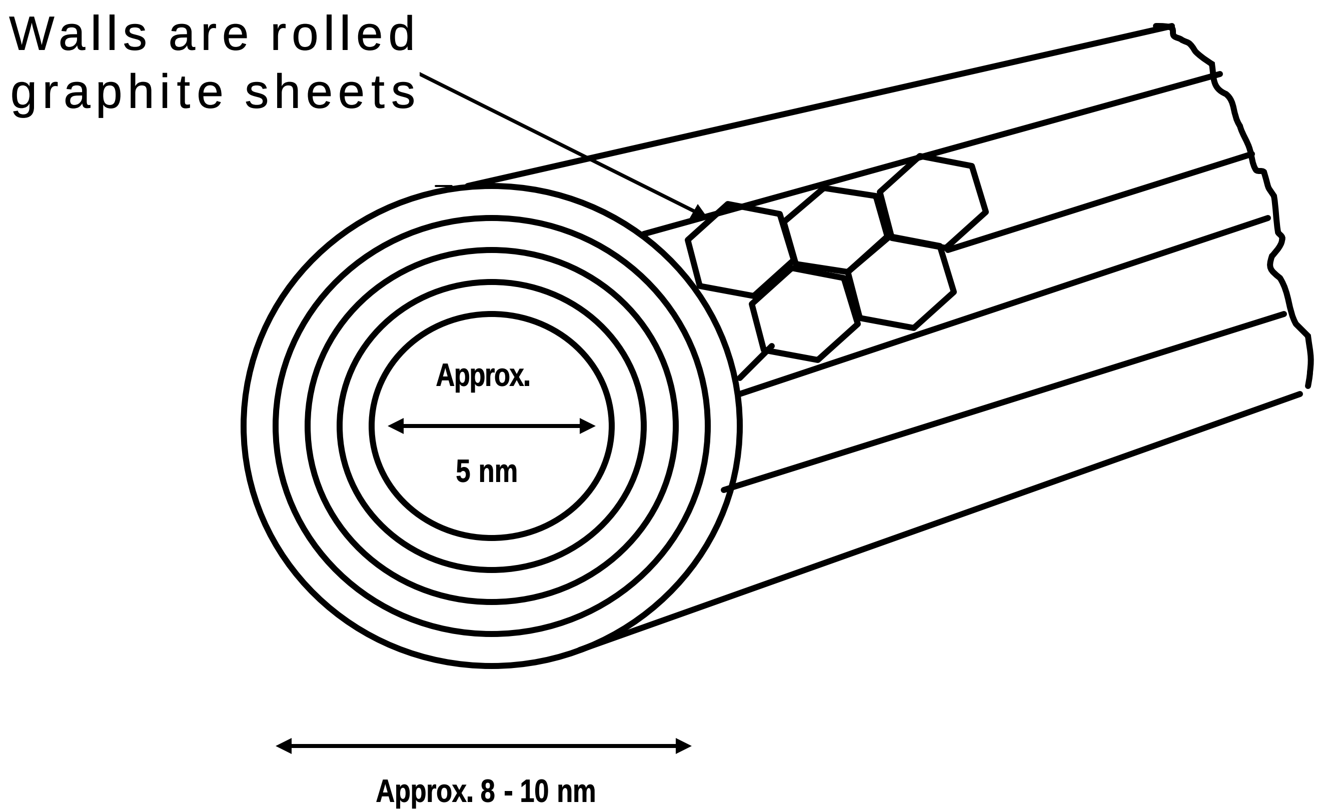
Outline

- Introduction to nanotubes
- Comparison of nanotubes to other conductive additives
  - Retention of resin physical properties
  - Cleanliness
- Applications for nanotubes in plastic

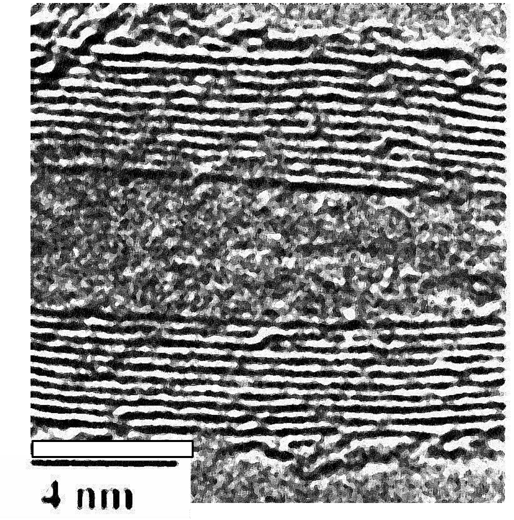
Structure of a Multiwall Nanotube

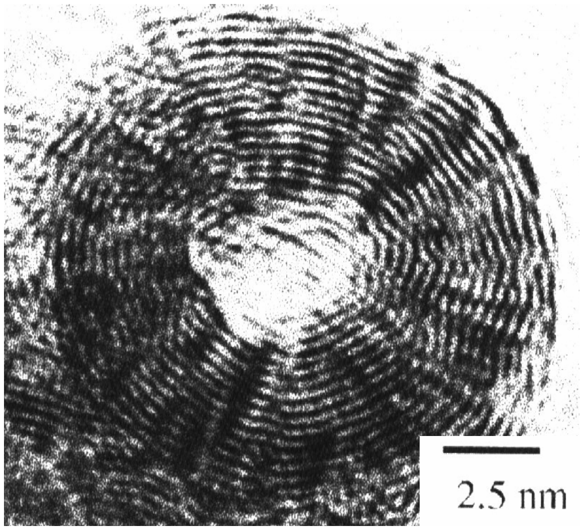
Hollow, multi-layer, graphitic carbon structure

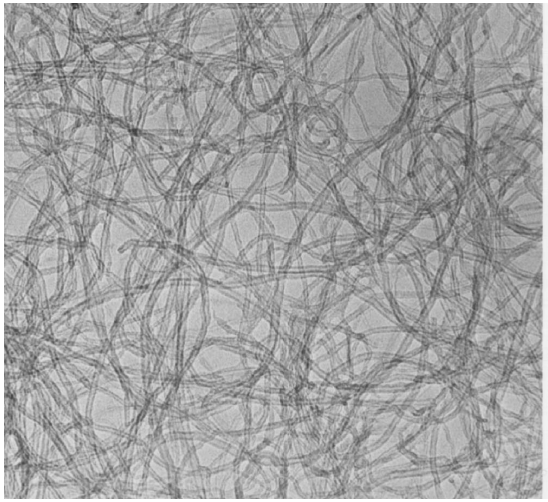


Structure of Nanotubes

- Approx. length: 10,000 nanometers
- Curvilinear rather then perfectly straight
- Aspect Ratio: Length/Diameter = 1000:1







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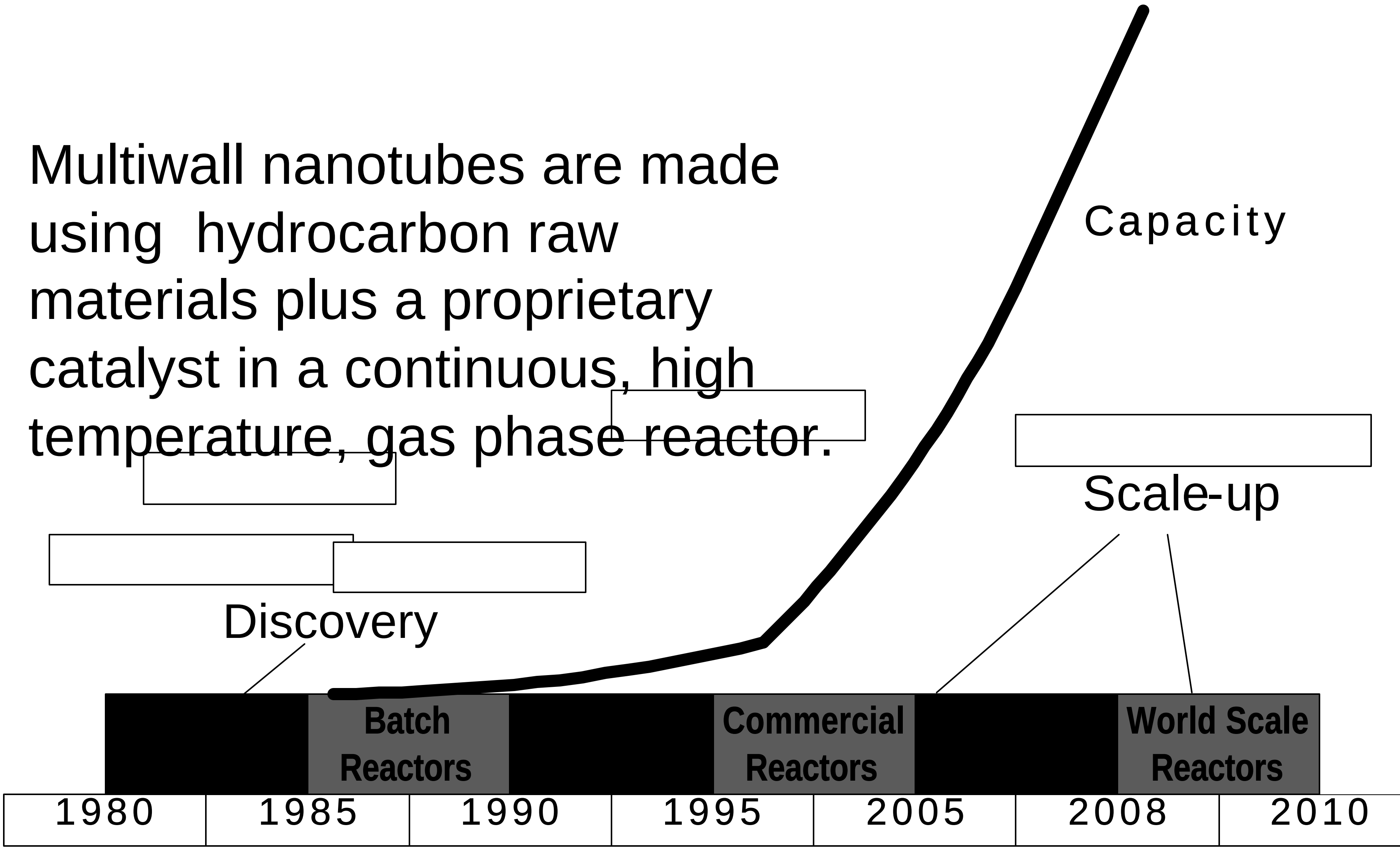
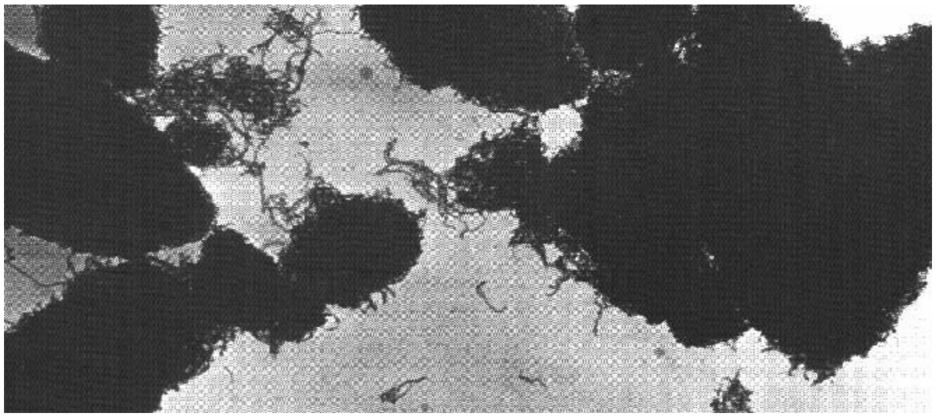
Multiwall Nanotube Chronology

Multiwall nanotubes are made using hydrocarbon raw materials plus a proprietary catalyst in a continuous, high temperature, gas phase reactor.



As-made Nanotubes Aggregate



Aggregates are intertwined bundles of nanotubes.

Approximate diameter:
1 – 10 microns.

- Untreated aggregates are difficult to separate into individual nanotubes.
- Hyperion has developed proprietary processes to disperse and incorporate nanotubes into various platforms.

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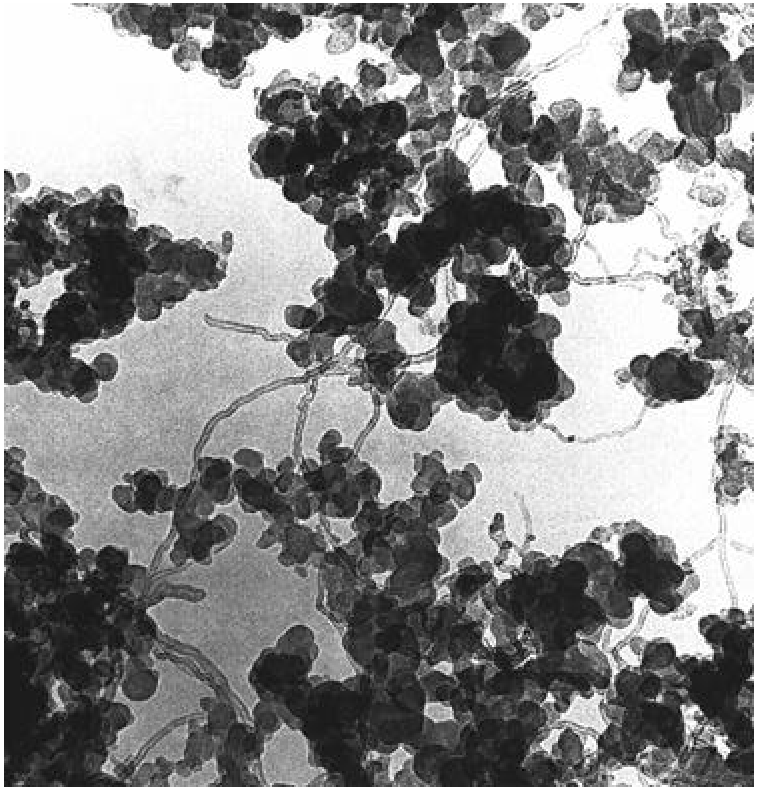
Comparison with Carbon Black



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- Nanotubes have a higher aspect ratio
- Nanotubes are more inert and more chemically pure

One long nanotube winds it’s way through the image.

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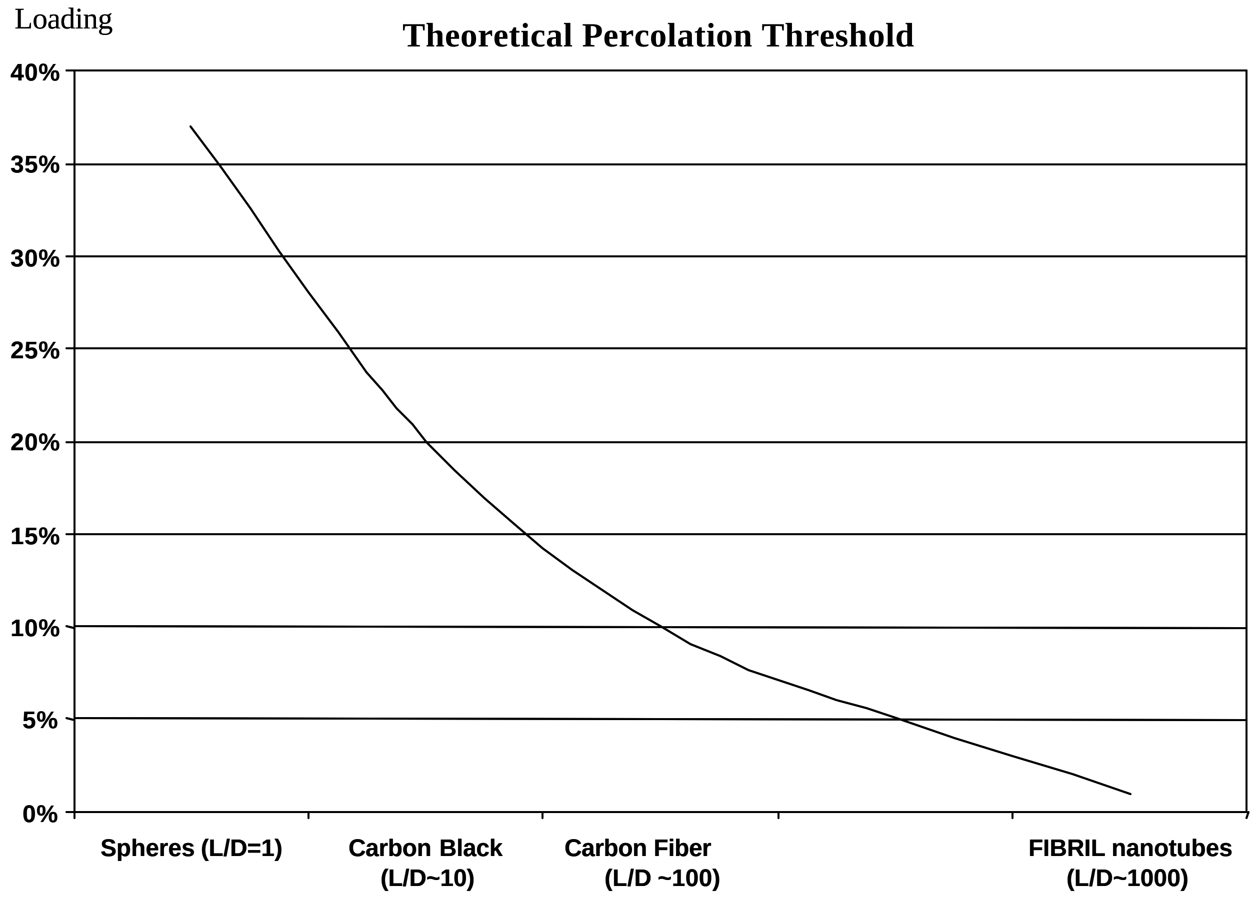
Comparison with Carbon Fiber

- Nanotubes are 1000 times smaller and have a higher aspect ratio
- Nanotubes have no sizing or coupling agents to compromise purity

Effect of Aspect Ratio on Loading

High Aspect Ratio Means Low Loading Needed To Impart Electrical Conductivity



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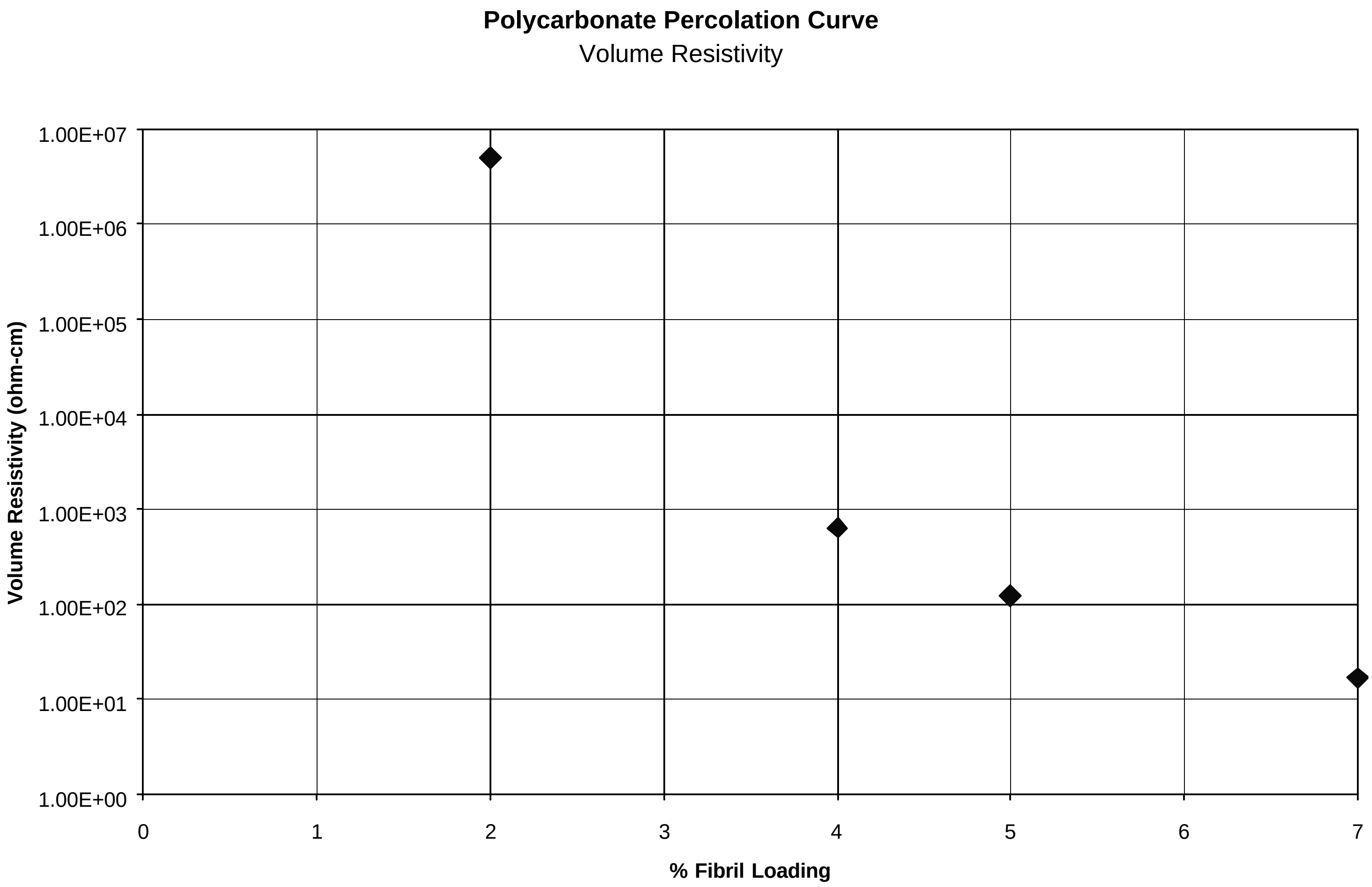
Nanotubes as Conductive Additive

2% in Polycarbonate Gives ESD Conductivity



Conductive Additive Comparison

Retention of resin physical properties

Study done by CRIF in Belgium in PC/ABS

- **Carbon Black**
- **Carbon Fiber**
- **Carbon Nanotubes**

CENTRE DE RECHERCHES SCIENTIFIQUES ET TECHNIQUES DE L'INDUSTRIE DES FABRICATIONS METALLIQUES

CRIF

Commercial PC/ABS Compounds

Formulated To Similar Level Of Surface Resistivity

Additive	Loading wt%	Volume Resistivity (ohm-cm)	Surface Resistivity (ohms)
None		10^{16}	n.a.
Nanotubes	7.3	10^{1} - 10^{3}	10^{4} - 10^{6}
Carbon Black	16.7	10^{3}	10^{6}
Carbon Fiber	13.7	10^{3}	10^{6}

Effect on Ductility

Nanotubes Give Least Reduction In Ductility

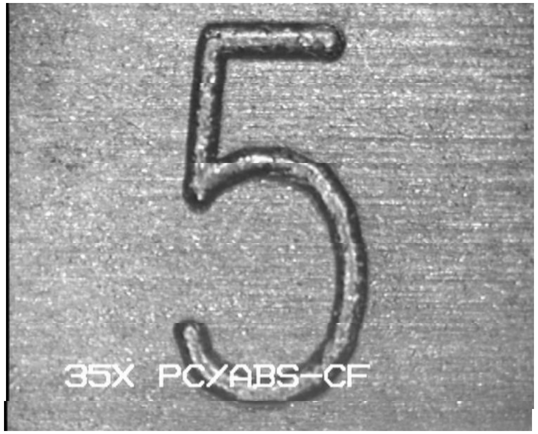
Additive	Loading wt%	Elongation at Break (%)	Un-Notched Izod (ft lbs)
None		100	NB
Nanotubes	7.3	10+	30
Carbon Black	16.7	3	10
Carbon Fiber	13.7	1 - 3	4

Effect on Part Surface

Nanotubes Give Smoothest Part Surface

Nanotubes

Carbon Black



Carbon Fiber

Effect on Part Surface

Nanotubes Give Smoothest Part Surface

Additive	Loading wt%	Ra microns
None		0.019
Nanotubes	7.3	0.025
Carbon Black	16.7	0.035
Carbon Fiber	13.7	0.426

Ra is the arithmetic average of the surface roughness

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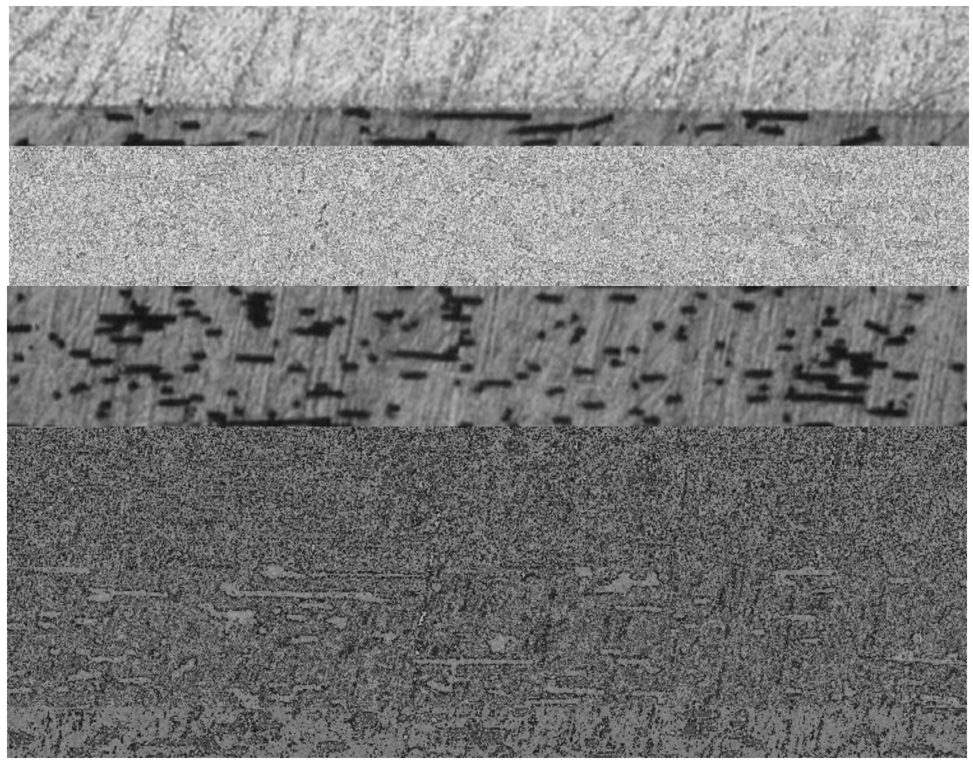
Distribution in Part

Carbon Fiber Oriented by Shear Fields

X230



Shear orientation can lead to warpage, unbalanced part strength and unbalanced part conductivity.

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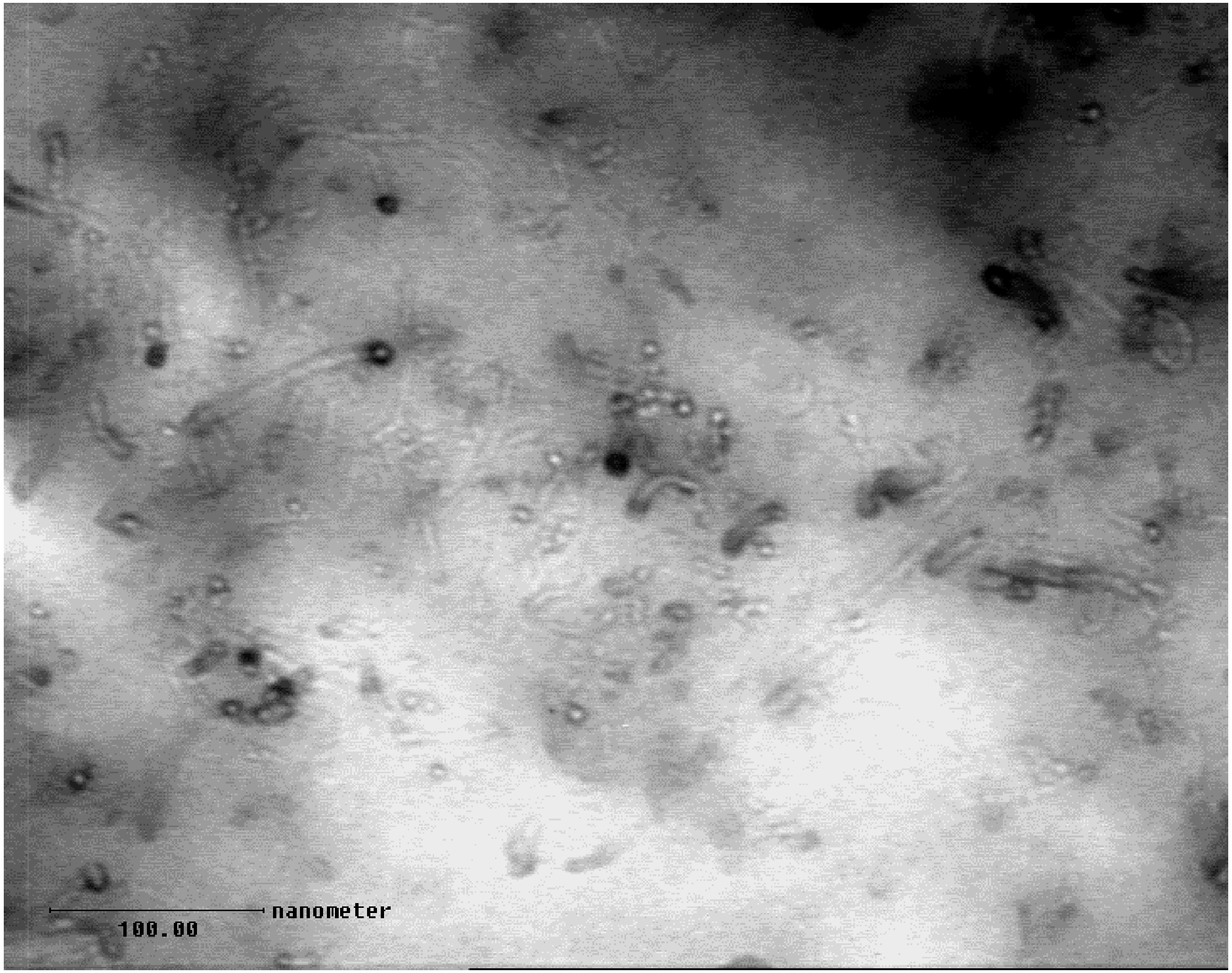
Distribution in Parts

Nanotubes Affected Very Little by Shear



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Effect on Part Uniformity

Nanotubes Give Balanced Flow/Cross-flow Shrink

Additive	Loading wt%	Differential Shrinkage
None		1.03
Nanotubes	7.3	0.96
Carbon Black	16.7	0.97
Carbon Fiber	13.7	0.92

Differential Shrinkage is the ratio of shrinkage in the flow direction divided by shrinkage in the transverse direction.

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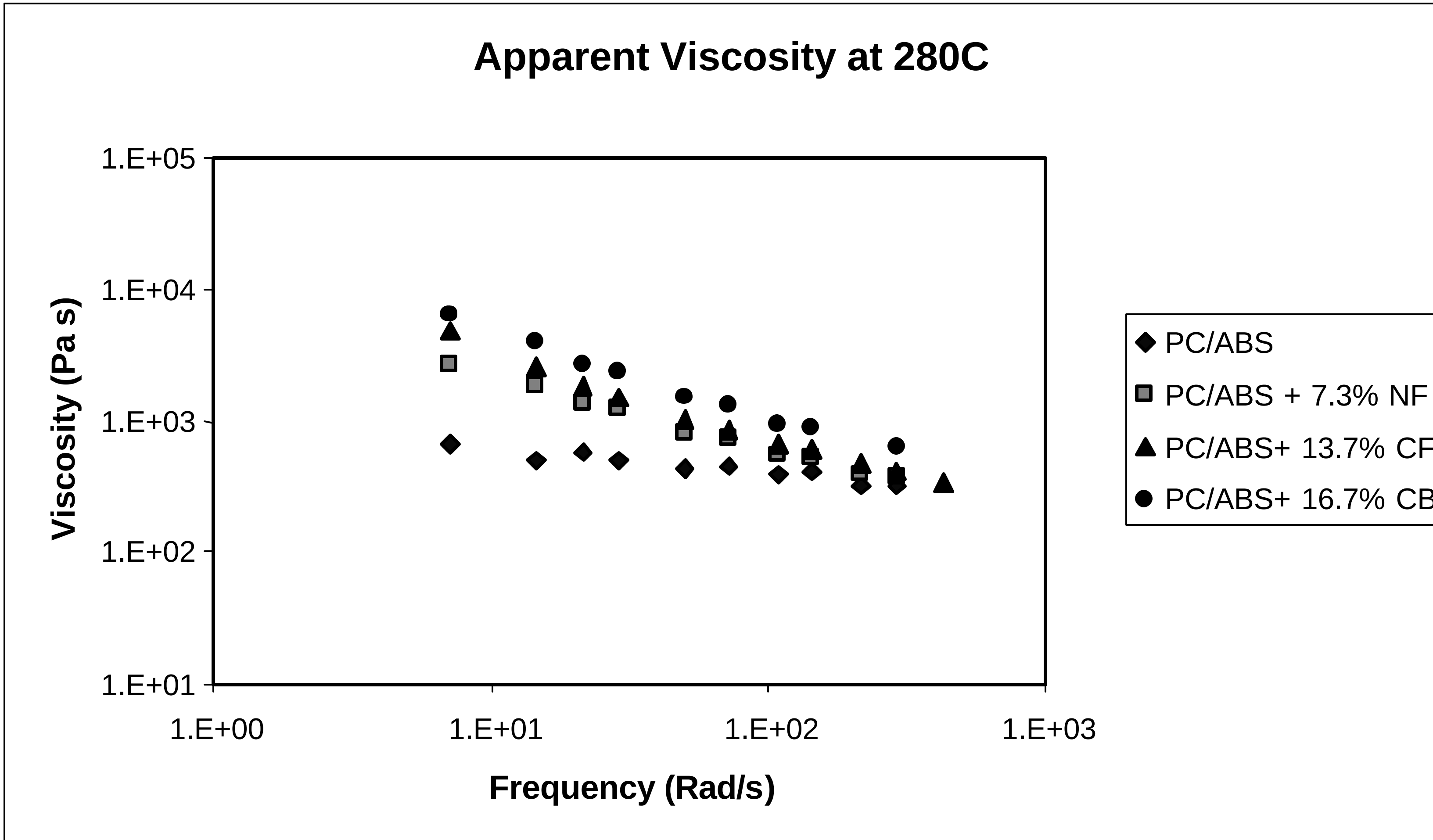
Effect on Resin Viscosity

Nanotubes Have Least Effect on Viscosity



Nanotubes in Plastics

Summary of Resin Physical Properties

- Low Loading
  - Minimal Effect on Resin Properties
  - Minimal Effect on Resin Viscosity
- Small Size
  - Excellent Part Surface Quality
  - Highly Isotropic Distribution Within Part

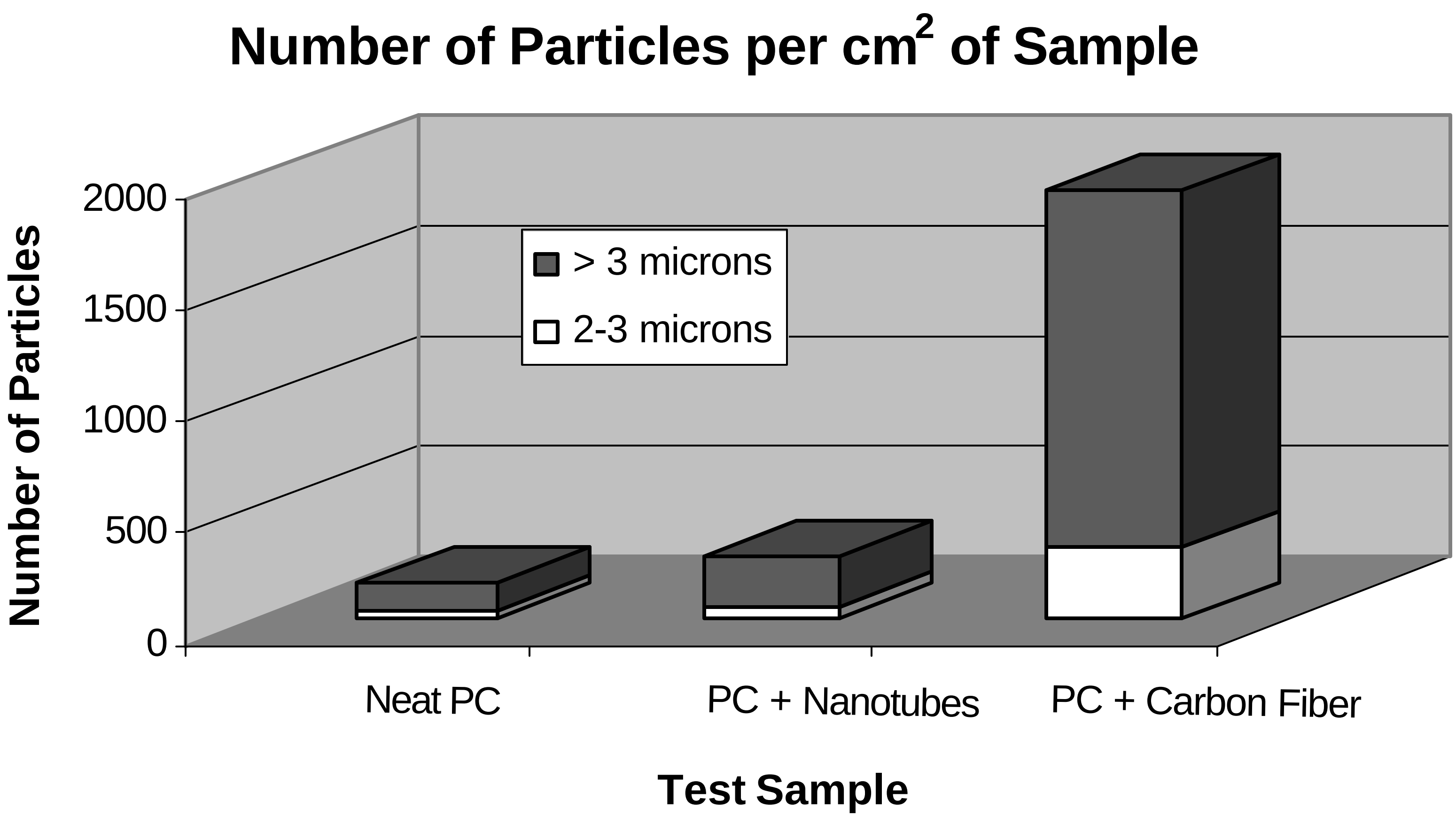
Conductive Additive Comparison

Cleanliness: Critical in clean room environments

- Sloughing (rub-off) of particles can contaminate critical work-in-process
- Frictional wear can lead to sloughing
- Outgasing of volatile chemicals can contaminate critical electronic or other components

Particle Sloughing

Measured by liquid particle count (LPC)



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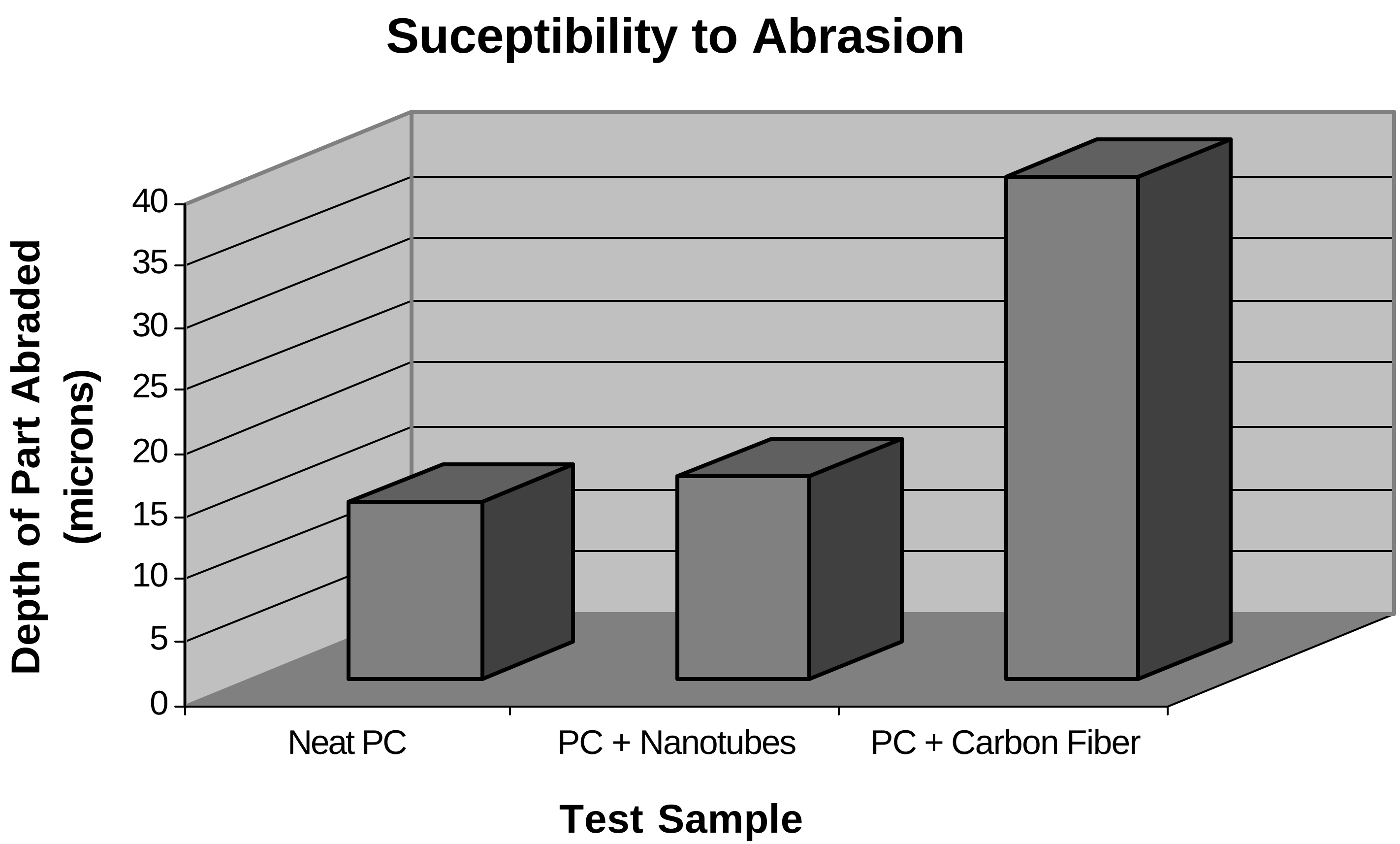
Resistance to Abrasion

Measured by depth of abrasion by sliding glass



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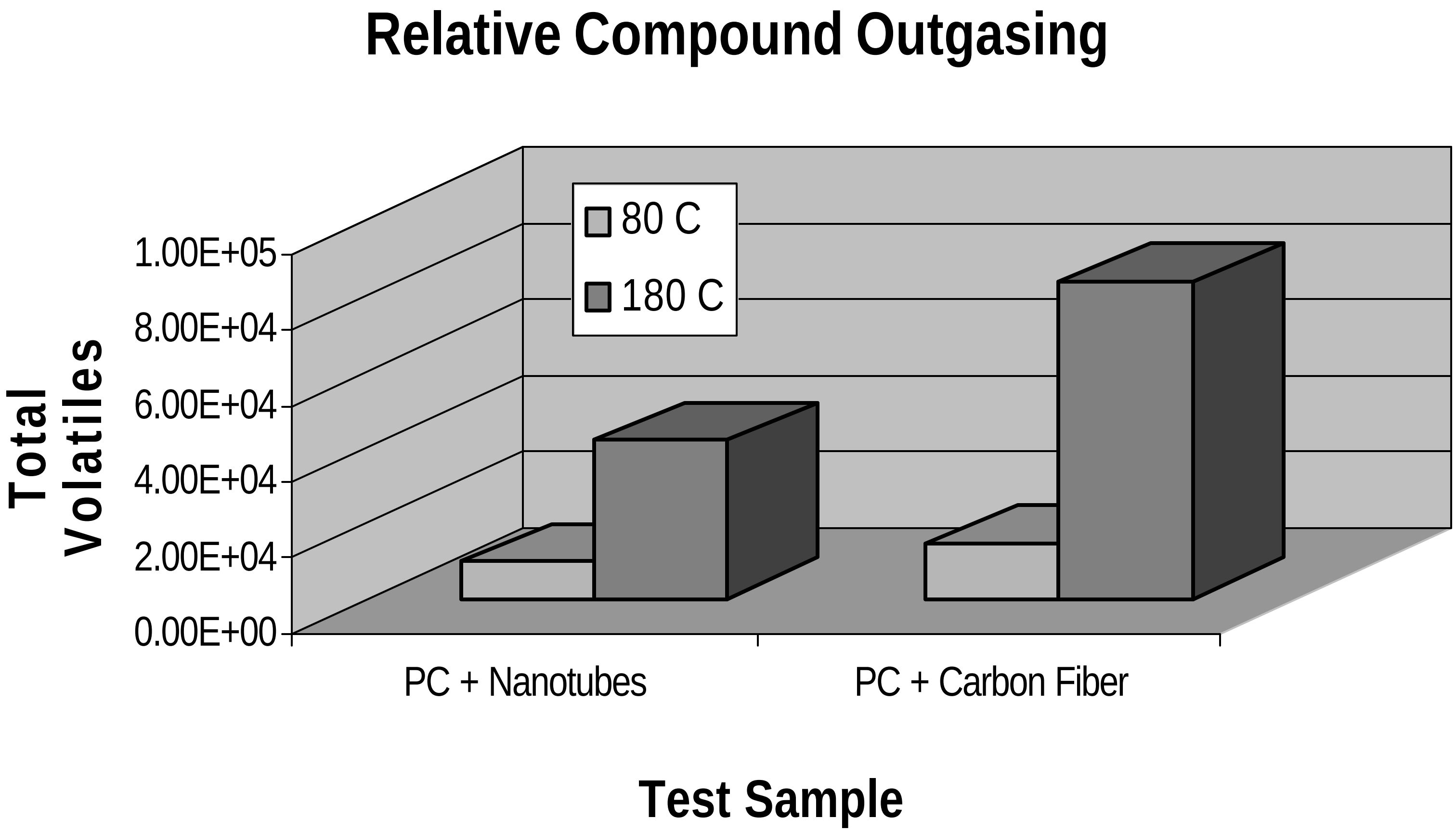
Outgasing of Volatiles

Measured by gas phase chromatography (GC)



Nanotubes in Plastics

Summary of purity

- Less sloughing
- Less abrasion
- Less outgasing

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Commercial Applications