Nanomaterials in Advanced Composites

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Hexcel

Agenda

- **Who is Hexcel?**
- **History of nanomaterial research in Hexcel**
- **Nanomaterials and their effects in advanced composites**
  - Carbon nanomaterials
  - Inorganic and organic nanomaterials
- **Nano hype**
- **Health and Safety**
- **Conclusions**

Hexcel: Company Profile

- Technology leader in advanced composites
- Serving commercial aerospace, space & defense and industrial
- Net Sales 2012: $1.58 Billion
- 5,000 employees worldwide
- 19 manufacturing sites (including JV in Malaysia)
- Headquarters in Stamford, CT, USA
- Listed on New York and Paris Stock Exchanges





Hexcel – Leader in Advanced Composites

Carbon Fiber

- A350 fuselage
- F-35 wings

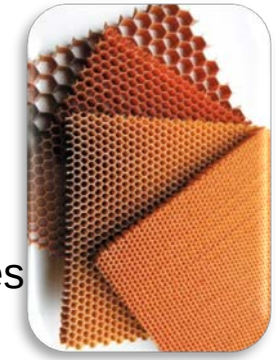
Glass Prepregs

- Wind blades
- Wing-to-body fairings in aero

Key properties
Fatigue and corrosion resistant
Light weight (density)
High Strength (tensile)
Stiffness (modulus)

Reinforcements

- Aircraft radomes
- Lamborghini roof



Honeycomb

- Helicopter blades
- Aircraft flooring
- Engine nacelle structures
- Acousti-Cap®

Carbon Prepregs

- A380 Central Wing Box
- GE90 Fan blade
- Eurofighter Tail

Engineered Products

- Structural Assemblies
- HexMC® parts
- Machined Core
- HexTool® Tooling System

Broad Range of Composite Materials and Applications

Nanomaterials in Hexcel

History of Nanomaterial Research at Hexcel

- **2000-2001 Initial nanomaterial research started**
- **2002 Suppliers approach Hexcel with products and requests for collaboration**
- **2004:**
  - Good composite data starts to be obtained
  - Extensive research in several sections of Hexcel R&T
  - 15+ NDAs in place with suppliers
  - First effects from CNFs on composite properties
- **2005 First customer evaluations take place of new products containing nanomaterials**
- **2007 First products launched**
- **2008 Nanomaterials become part of the formulators' regular toolkit**

Changes in Nanomaterial Evaluation at Hexcel

- **Evolution of additives, becoming more sophisticated**
  - Suppliers have worked with Hexcel, leading to product evolution
  - Materials are available pre-dispersed in a wider range of base resins
  - More materials are functionalised for matrix interaction
- **Evaluation of matrices and composites has improved**
- **Work with suppliers has changed**
  - Initially, as supplier to customer
  - A phase of active collaboration
  - A sceptical phase after limited positive results
- **Hexcel now asks for evidence before evaluation**
- **Suppliers now approach Hexcel's customers directly!**

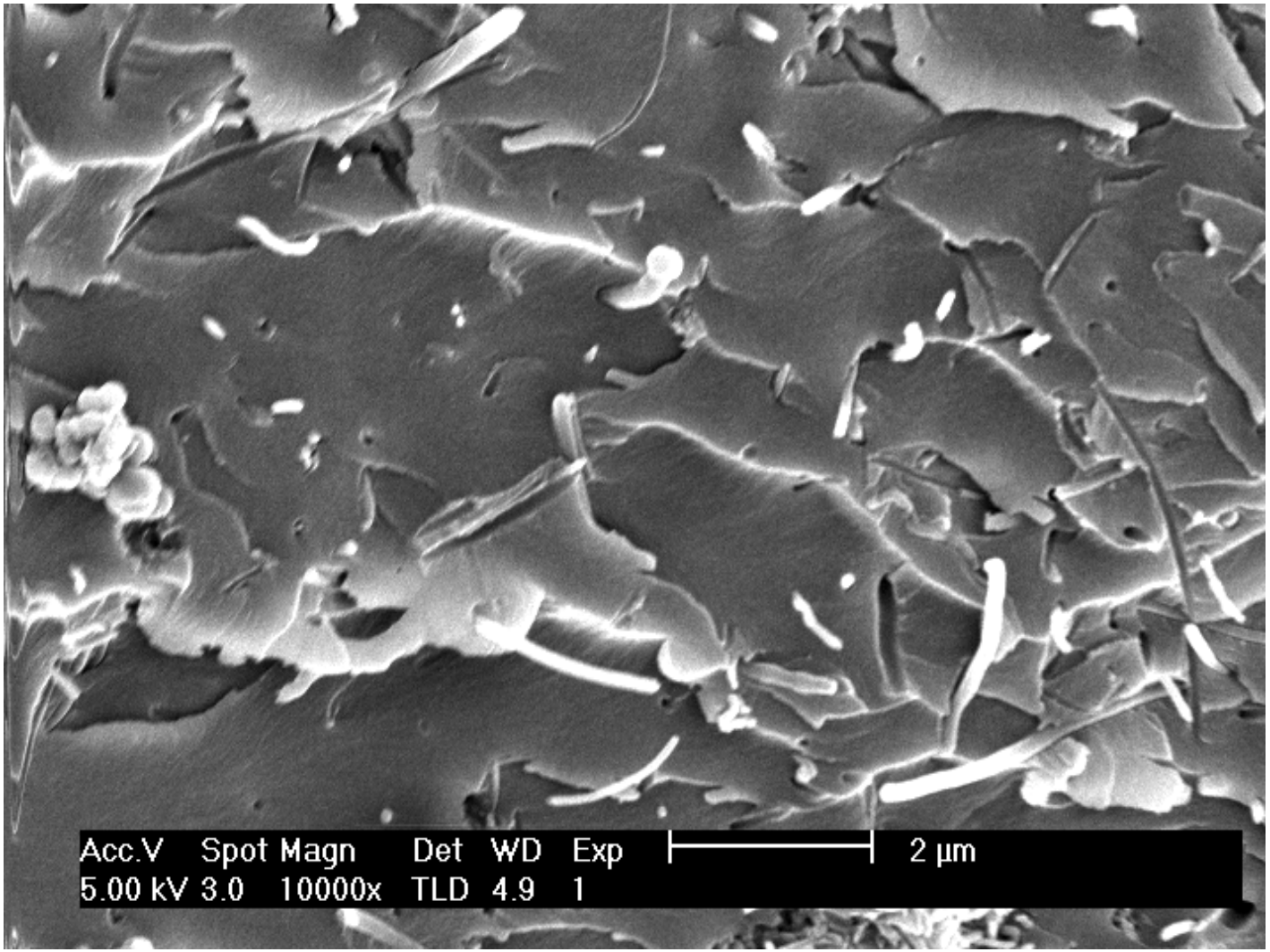
Examples of Nanomaterials

- **Carbon**
  - Nanofibres (CNFs)
  - Nanotubes (CNTs: SWNTs, MWNTs)
  - Graphite platelets/ graphene
- **Organic**
  - Spherical particles
  - Copolymers
- **Inorganic**
  - Clays
  - Silica
  - Silicon carbide
  - Alumina and other metal oxides
  - Polyhedral oligomeric silsesquioxane (POSS)

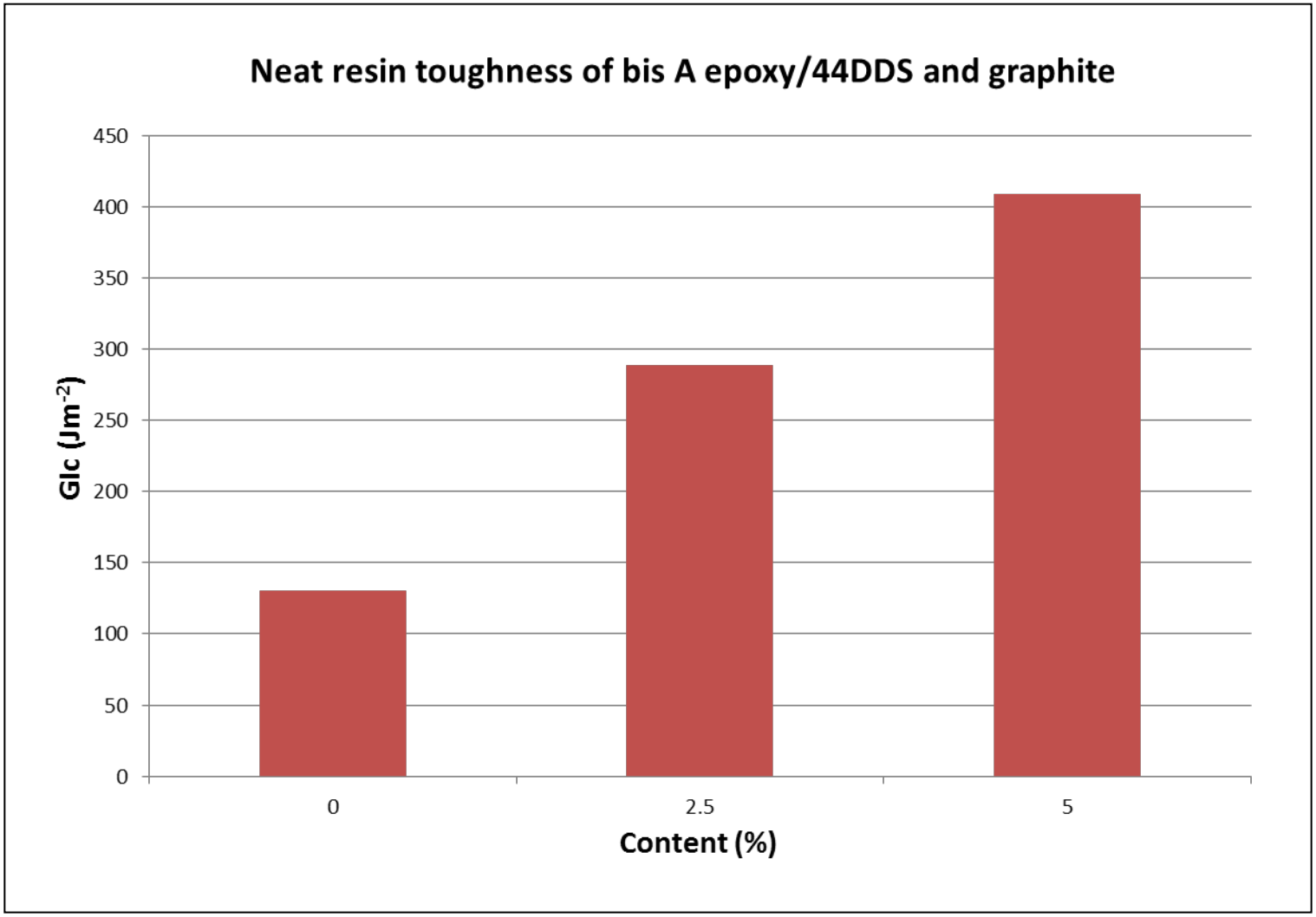
Carbon Materials – Key Properties

	Diameter	Length	Modulus	Strength
Carbon fibres	~8000 nm	*continuous*	230 – 725 GPa	2.5 – 5.5 GPa
CNFs	~100 nm	20-100 μ	100 – 1000 GPa	2.5 – 3.5 GPa
CNTs	1-100 nm	up to mms	>1 TPa	63 GPa
- SWNTs	~ 1nm	up to mms	0.32 – 1.47 TPa	10 – 52 GPa
- MWNTs	2 – 100 nm	tens of microns	0.27 – 0.95 TPa	11 – 63 GPa
Graphene	1-10 nm (thick)	1-20 microns	1 TPa	80 GPa

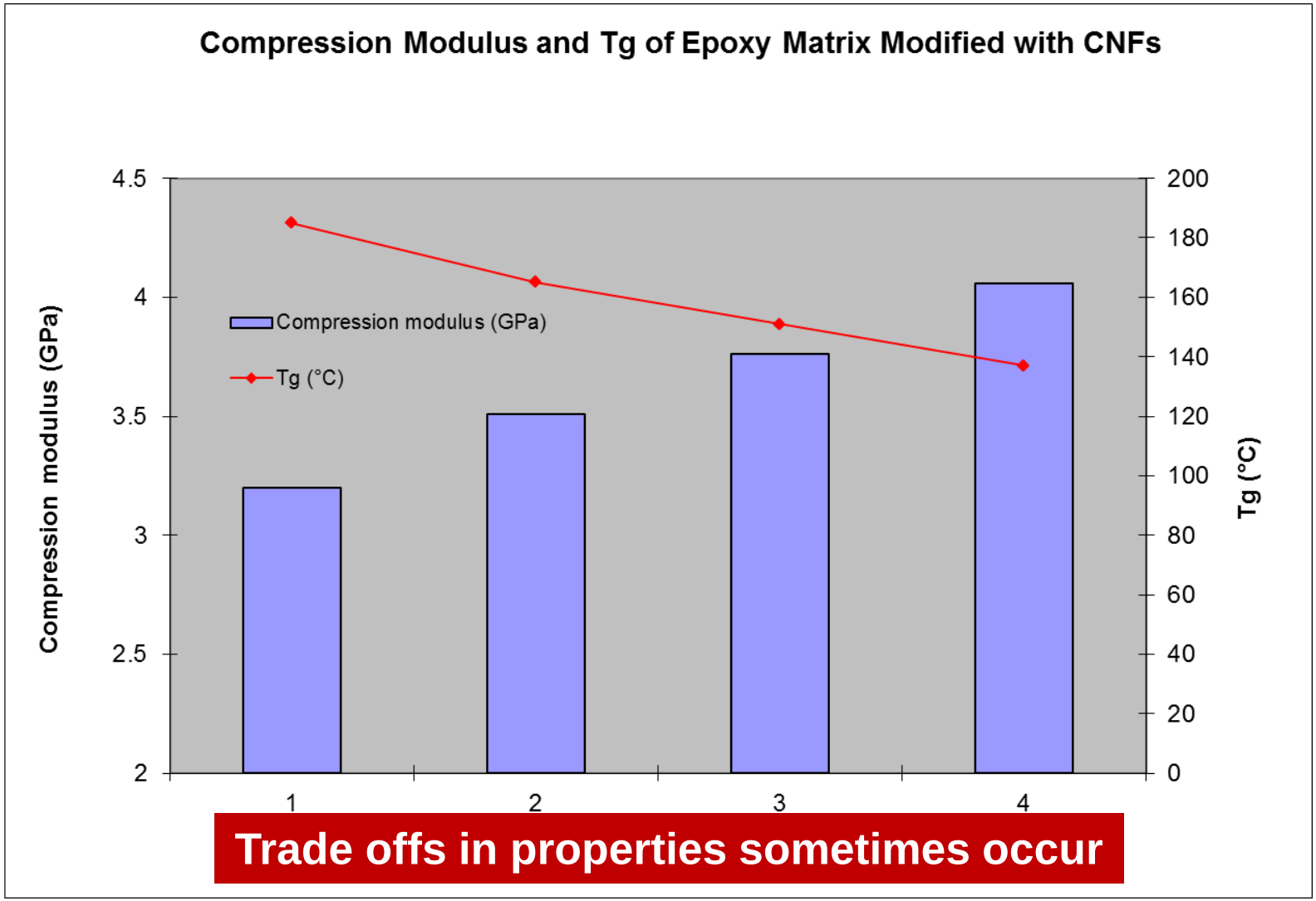
SEM of CNFs in Neat Resin



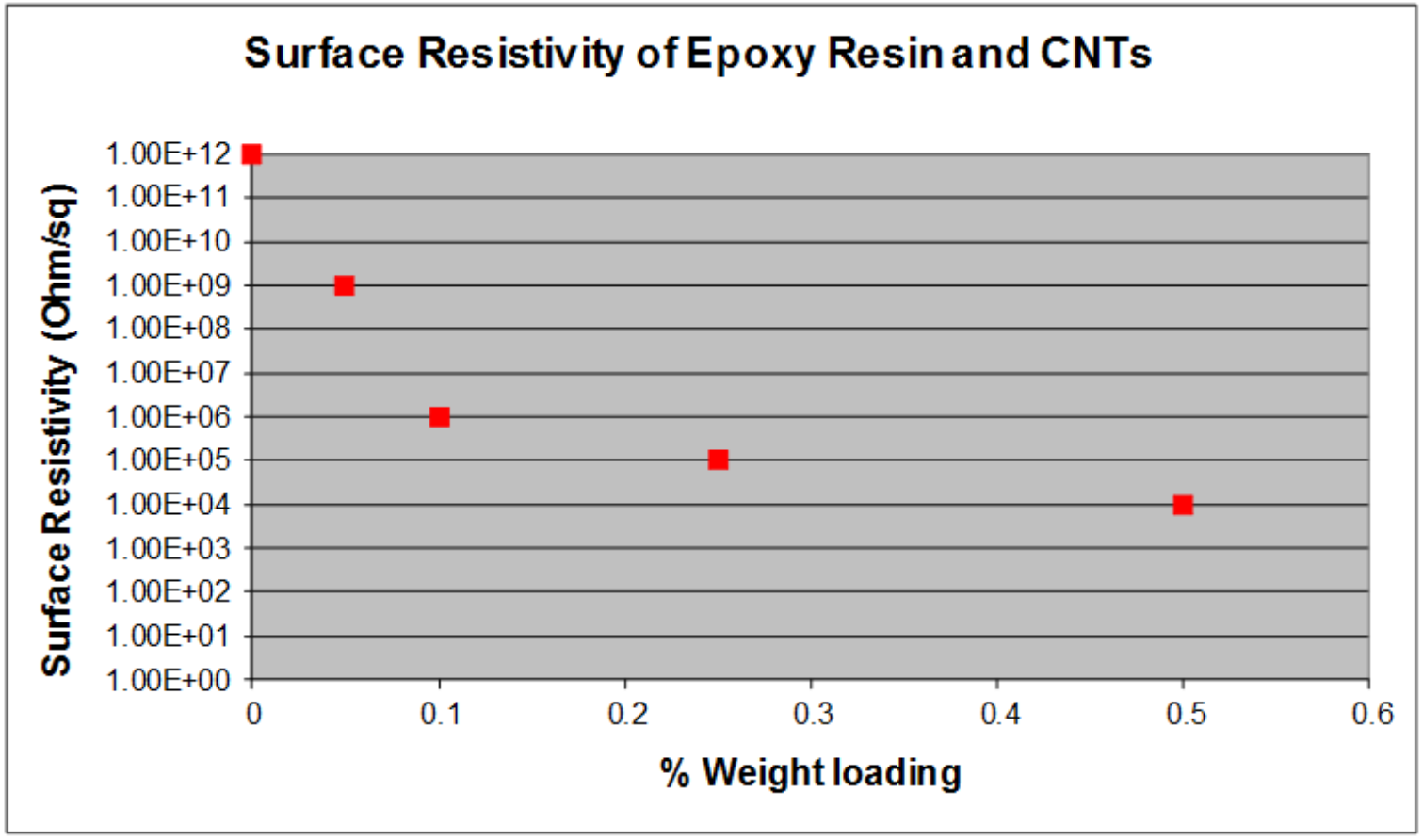
Effect of Graphite Platelets on Toughness



Effect of CNFs on Compression and Tg



Effect of CNTs on Surface Resistivity



Main Conclusions from CNFs and CNTs

- **Effective dispersion of carbon nanomaterials is difficult**
  - Strong tendency to form agglomerates
  - Quality of dispersion is key
  - Functionalisation is likely to be key
    - Several approaches to this have been taken
- **CNTs and CNFs can show effects in neat resin which are often lost in composite**
- **The size of these effects is often bettered by other more cost effective additives**
- **Raw material cost is an issue, perhaps just in the short term**
  - Costs will reduce as demand and scale increase

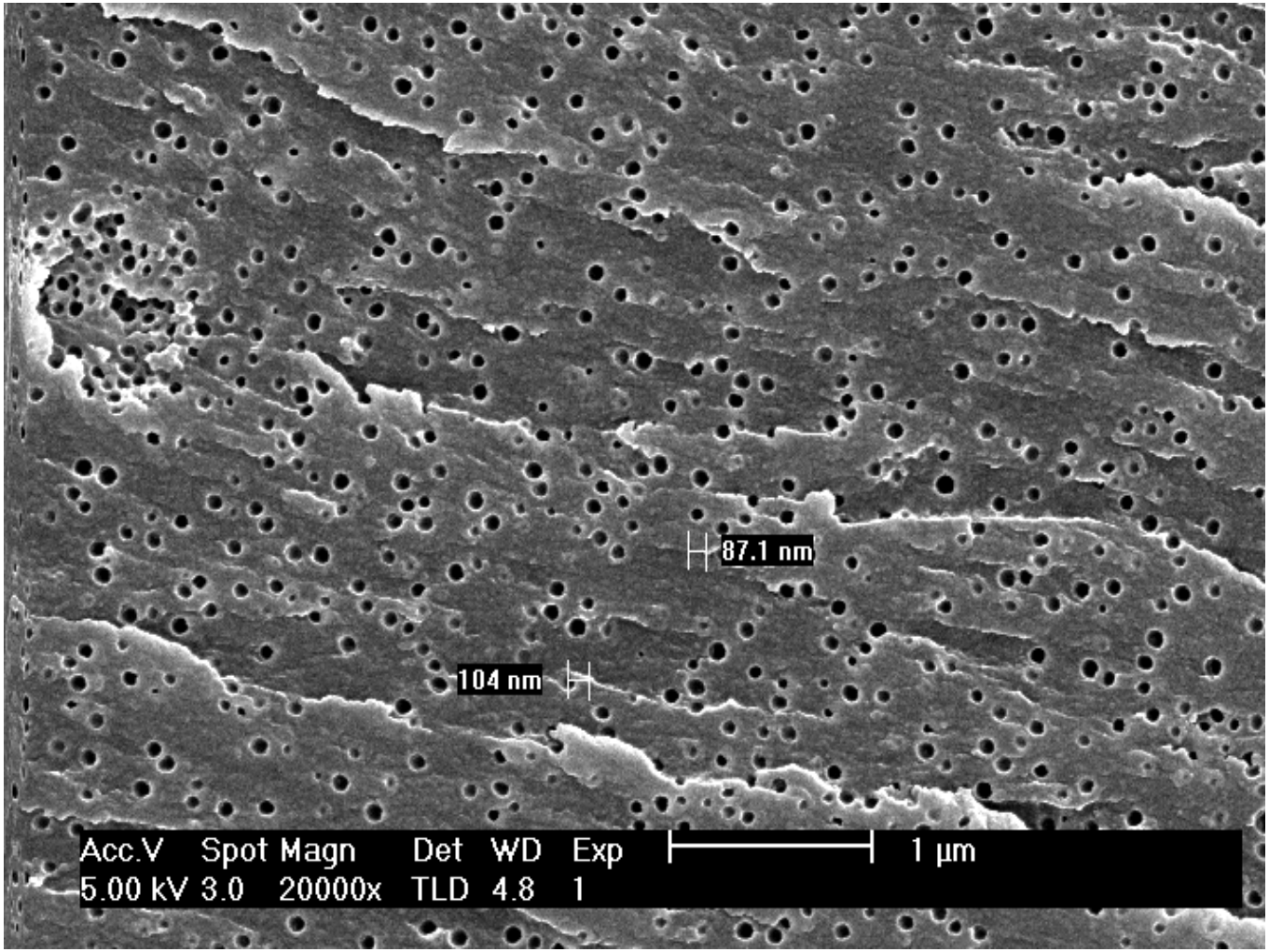
Cost of materials is not out-weighed by achievable benefits

Organic and Inorganic Nanomaterials

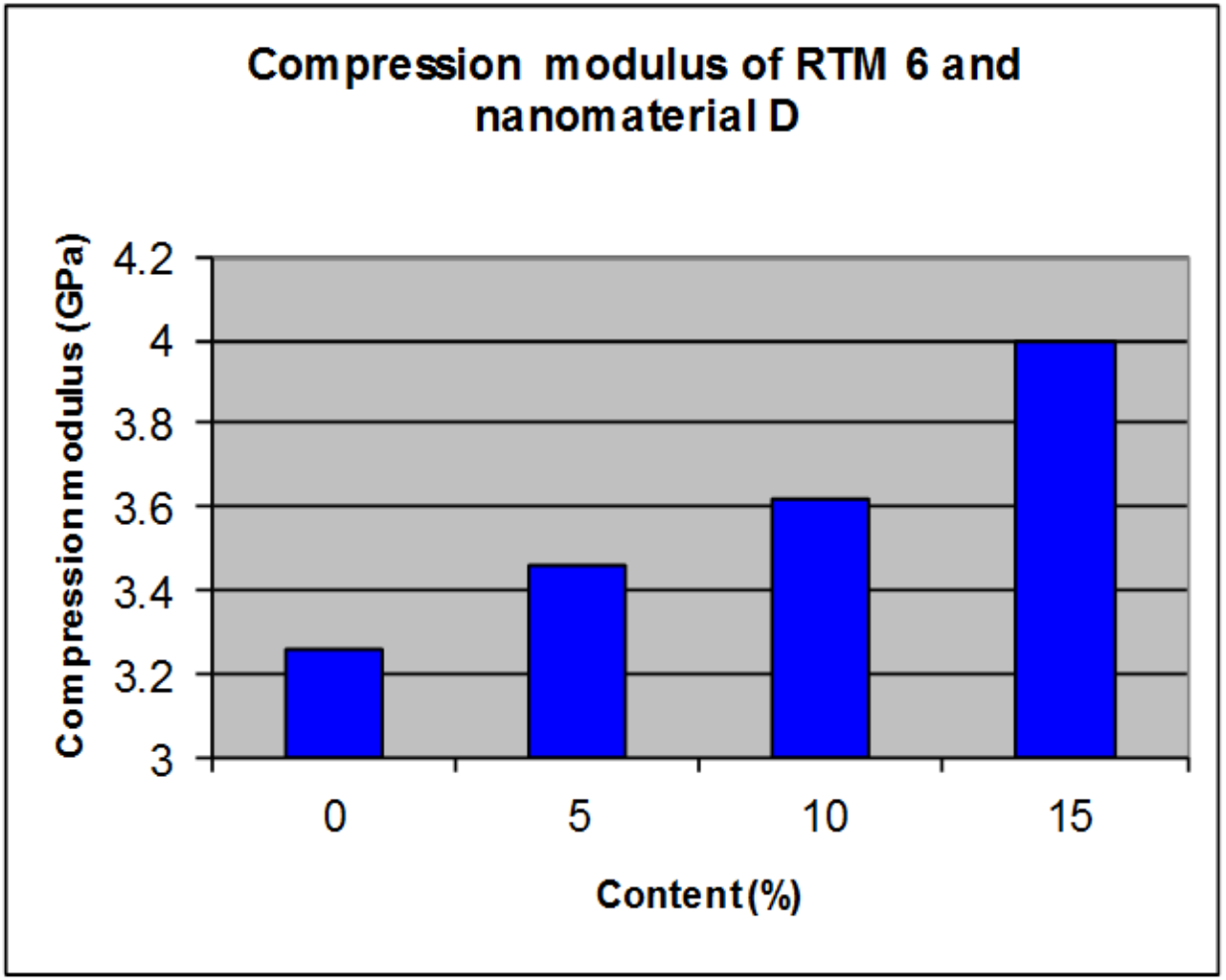
- **A wide range of (in)organic nanomaterials have been evaluated, including nano clays, silica, alumina, silicon carbide, polymers and co-polymers**
- **Dispersion tends to be easier**
- **Most materials are more readily available and more cost effective**
- **Positive effects have been found on the following properties:**
  - Compression modulus
  - Toughness
  - Fatigue resistance
  - Surface abrasion and scratch resistance
  - Surface finish

Clear benefits can be achieved from some materials, especially organic nanomaterials

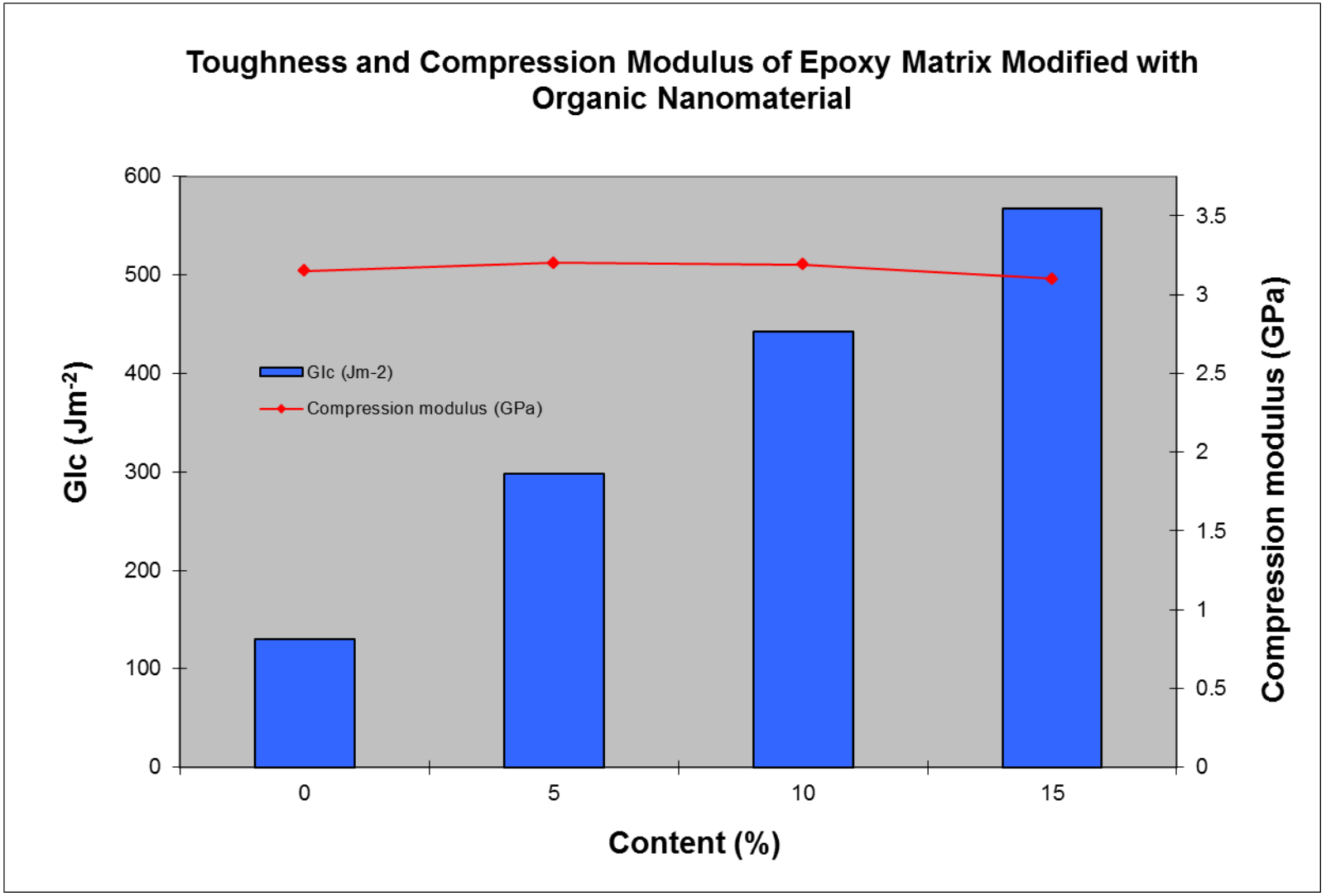
SEM of Nanomaterial Particles in an Epoxy Matrix



Effect of Nanomaterial on Compression of RTM6

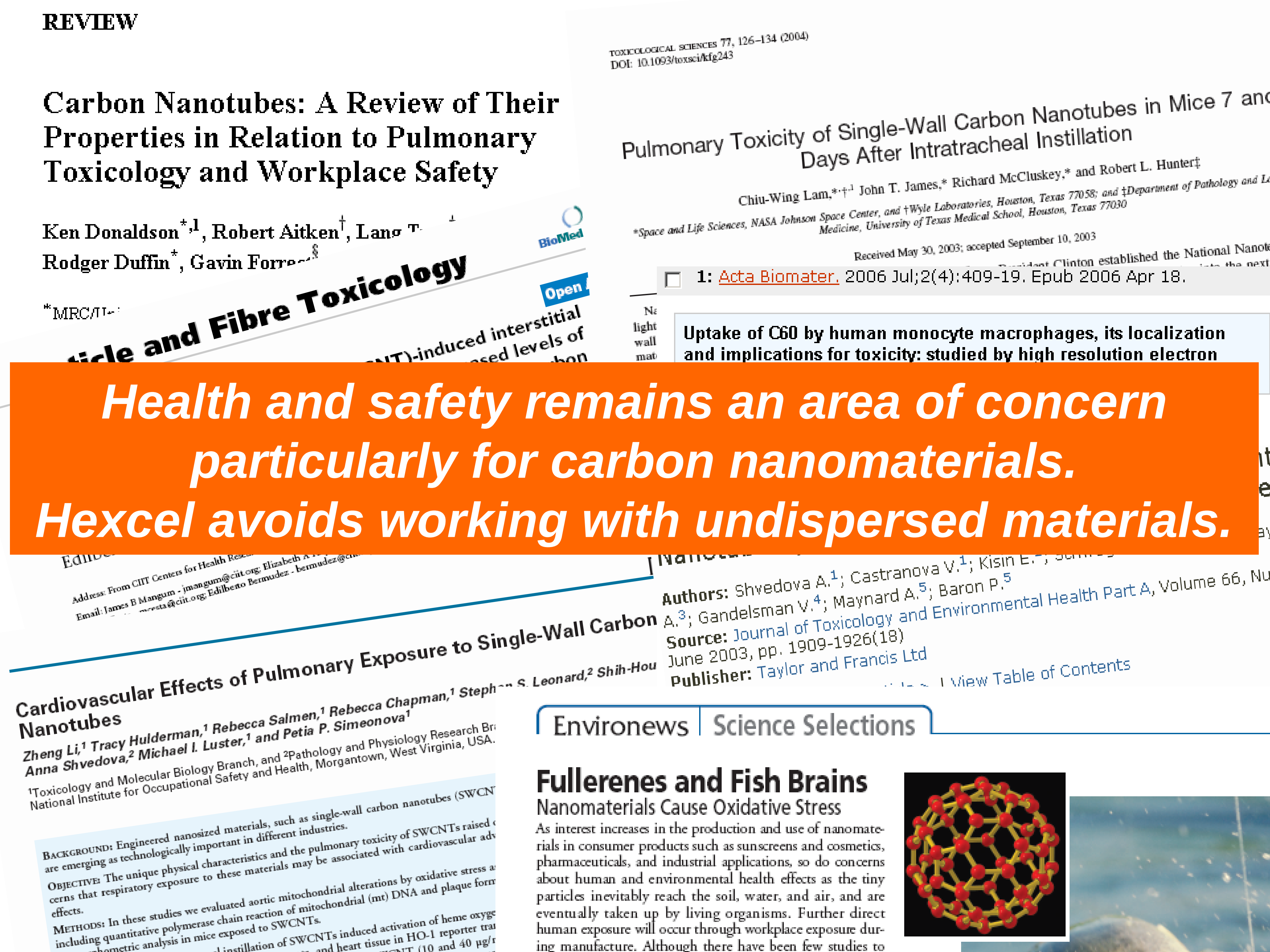


Effect of Nanomaterial on Neat Resin Mechanicals



Nano-hype

- **Nanomaterials are the subject of extensive research, and publicity**
  - This attracts extensive government, and other, funding
- **Many claims are made for these materials**
- **Little objective repeatable data is available**
- **Their potential has sometimes been over-inflated**
- **Hexcel's objectives for nanomaterial investigations are:**
  - To retain an open mind
  - To seek clear repeatable data that shows a cost effective benefit from the nanomaterial
  - To utilise these benefits in product development as fast as possible


REVIEW
Carbon Nanotubes: A Review of Their Properties in Relation to Pulmonary Toxicology and Workplace Safety
Ken Donaldson, Robert Aitken
Rodger Duffin
and Fibre Toxicology
BioMed
TOXICOLOGICAL SCIENCES 77, 126–134 (2004)
DOI: 10.1093/toxsci/kfg243
Pulmonary Toxicity of Single-Wall Carbon Nanotubes in Mice 7 and
Days After Intratracheal Instillation
Chiu-Wing Lam, John T. James, Richard McCluskey, and Robert L. Hunter
Received May 30, 2003; accepted September 10, 2003
1: Acta Biomater. 2006 Jul;2(4):409-19. Epub 2006 Apr 18.
Uptake of C60 by human monocyte macrophages, its localization and implications for toxicity: studied by high resolution electron
Health and safety remains an area of concern particularly for carbon nanomaterials.
Hexcel avoids working with undispersed materials.
Authors: Shvedova A.; Castranova V.; Kisin E.
Source: Journal of Toxicology and Environmental Health Part A, Volume 66
June 2003, pp. 1909-1926(18)
Publisher: Taylor and Francis Ltd
View Table of Contents
Cardiovascular Effects of Pulmonary Exposure to Single-Wall Carbon Nanotubes
Zheng Li, Tracy Hulderman, Rebecca Salmen, Rebecca Chapman
Anna Shvedova, Michael I. Luster, and Petia P. Simeonova
Toxicology and Molecular Biology Branch, and Pathology and Physiology Research
National Institute for Occupational Safety and Health, Morgantown, West Virginia, USA.
BACKGROUND: Engineered nanosized materials, such as single-wall carbon nanotubes are emerging as technologically important in different industries.
OBJECTIVE: The unique physical characteristics and the pulmonary toxicity of SWCNTs raised concerns that respiratory exposure to these materials may be associated with cardiovascular
METHODS: In these studies we evaluated aortic mitochondrial alterations by oxidative stress including quantitative polymerase chain reaction of mitochondrial (mt) DNA and plaque formation
Environews
Science Selections
Fullerenes and Fish Brains
Nanomaterials Cause Oxidative Stress
As interest increases in the production and use of nanomaterials in consumer products such as sunscreens and cosmetics, pharmaceuticals, and industrial applications, so do concerns about human and environmental health effects as the tiny particles inevitably reach the soil, water, and air, and are eventually taken up by living organisms. Further direct human exposure will occur through workplace exposure during manufacture.

Main Conclusions from Hexcel's Nanomaterials Work

- **Some materials work well**
  - These have become part of the formulators' tool kit
- **Some materials remain of unproven value because of lack of effect or because of cost compared with conventional materials**
- **The effects of nanomaterials, particularly in the undispersed state, on health need to be monitored**
- **Nanomaterials for composites need to lose their mystique**
  - The hype needs to cease

Nanomaterials have a role to play in advanced composites but they must be cost-effective

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