Hyperion Catalysis

52nd IWCS/FOCUS

Carbon Multiwall Nanotubes A Possible Additive for Conductive or Flame Retardant Use in Wire and Cable

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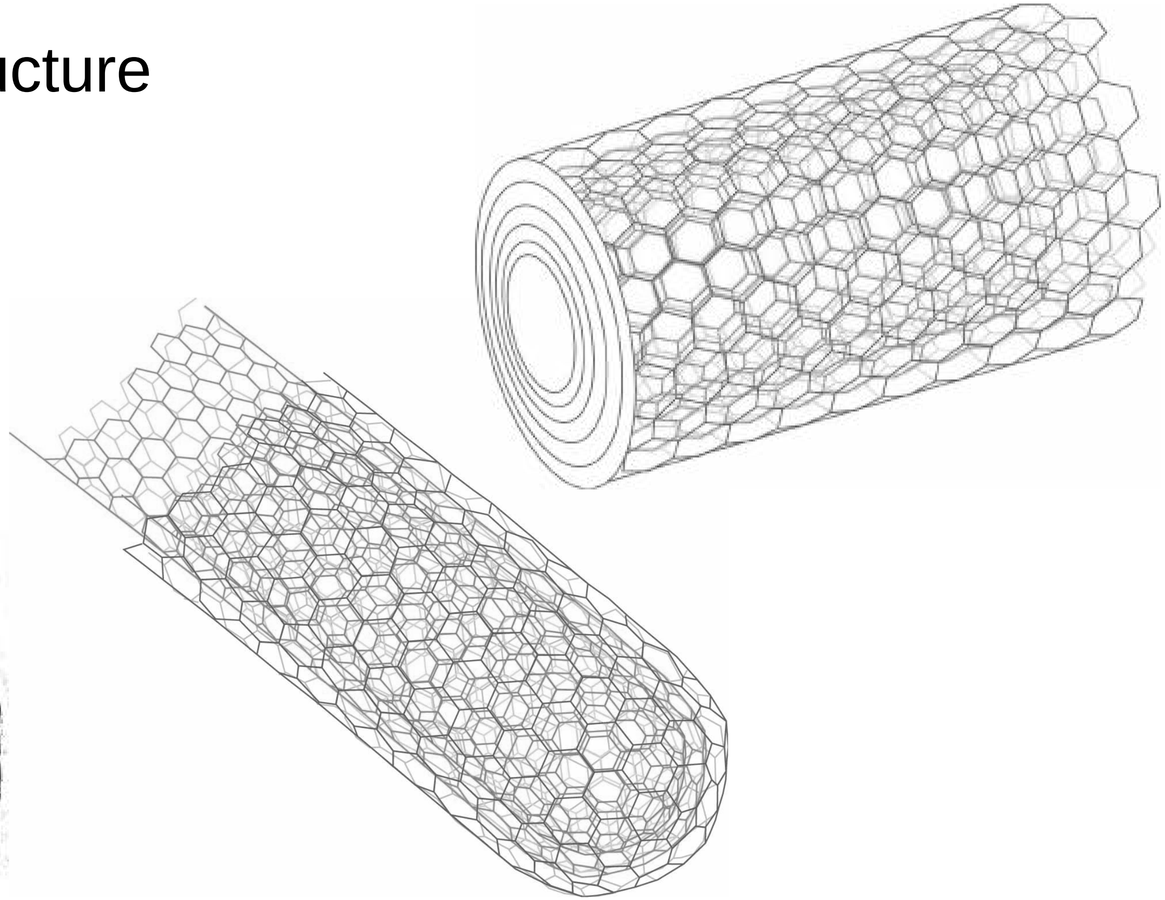
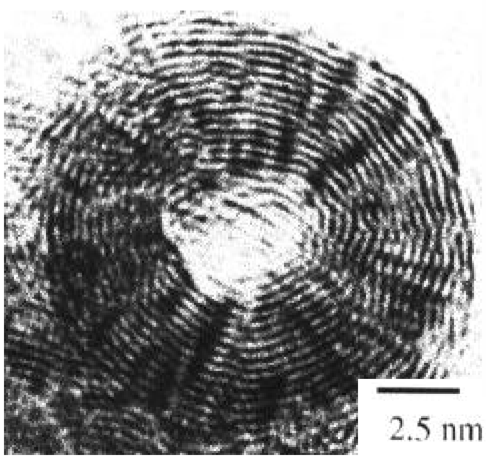
Structure of a FIBRIL™ Nanotube

A unique carbon structure

- Graphitic wall structure
- Multilayer
- Hollow





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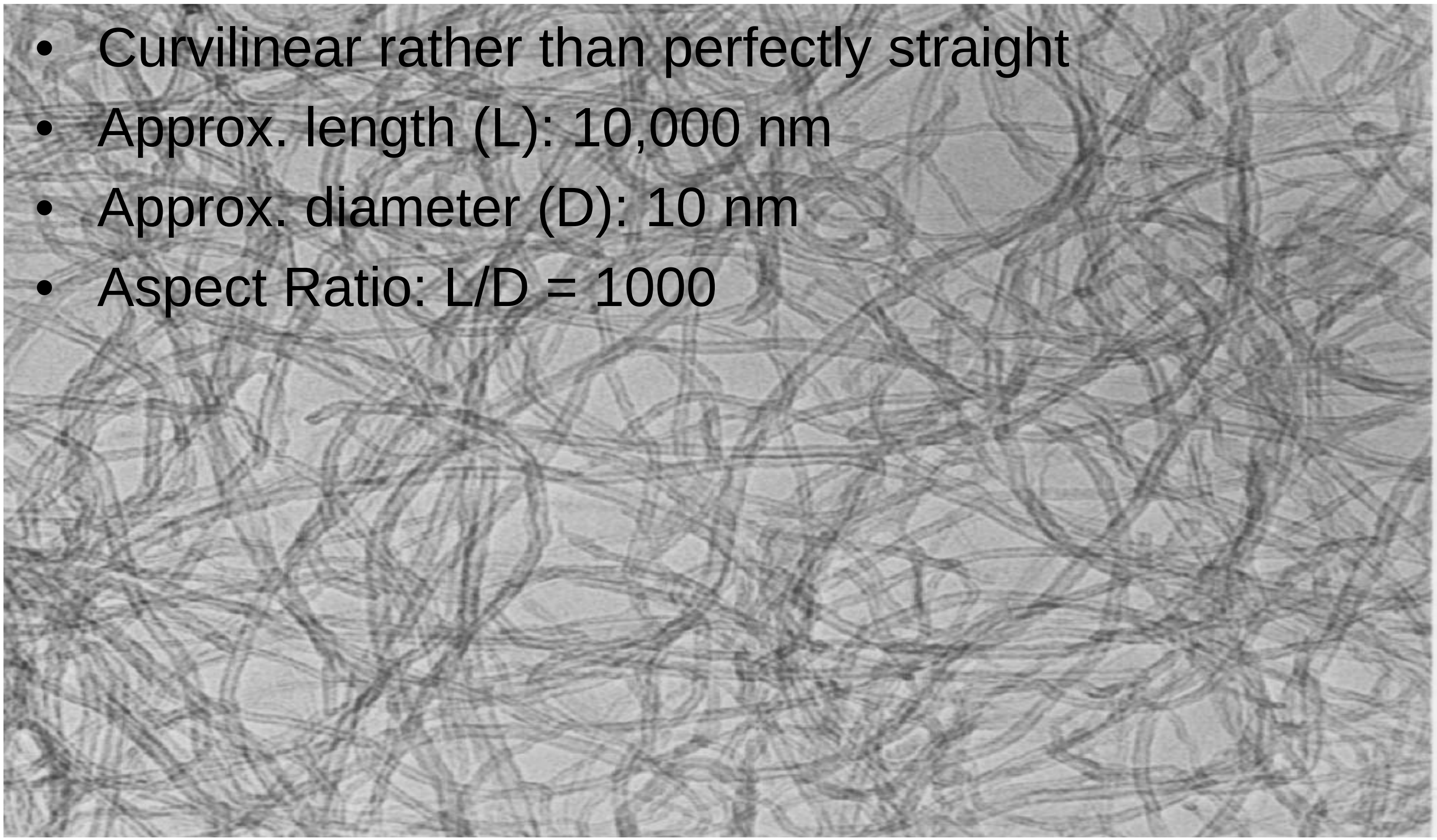
Structure of FIBRIL Nanotubes

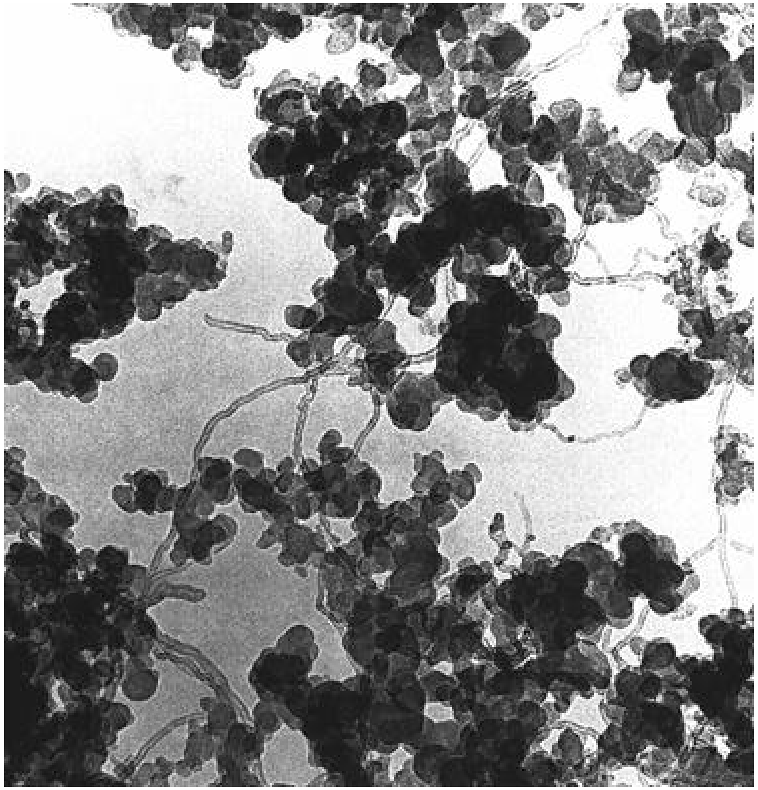
FIBRIL nanotubes form excellent networks



- Curvilinear rather than perfectly straight
- Approx. length (L): 10,000 nm
- Approx. diameter (D): 10 nm
- Aspect Ratio: L/D = 1000

Comparison with Carbon Black

Nanotubes are significantly different



- 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 significantly different

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

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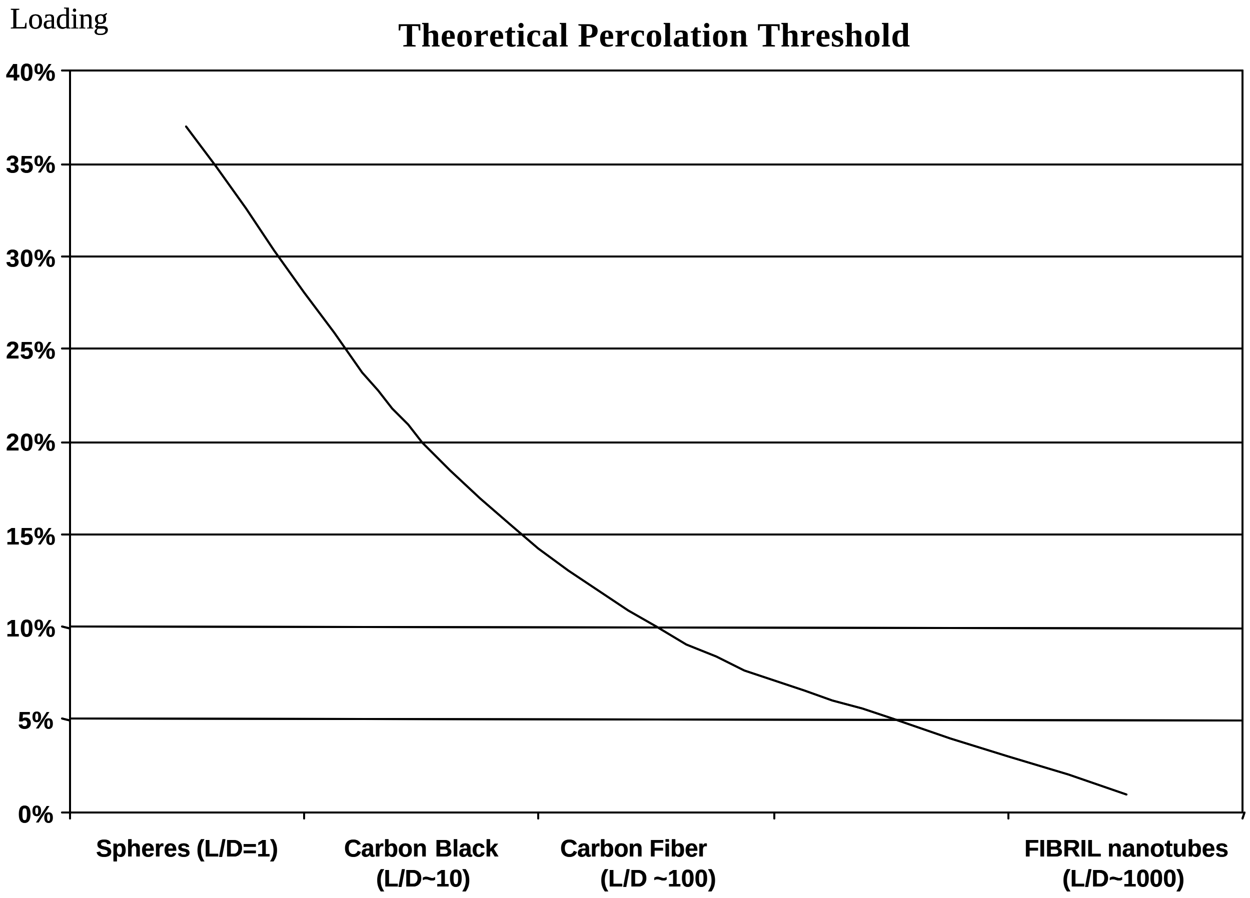
Effect of Aspect Ratio on Loading

High aspect ratio = low loading for conductivity



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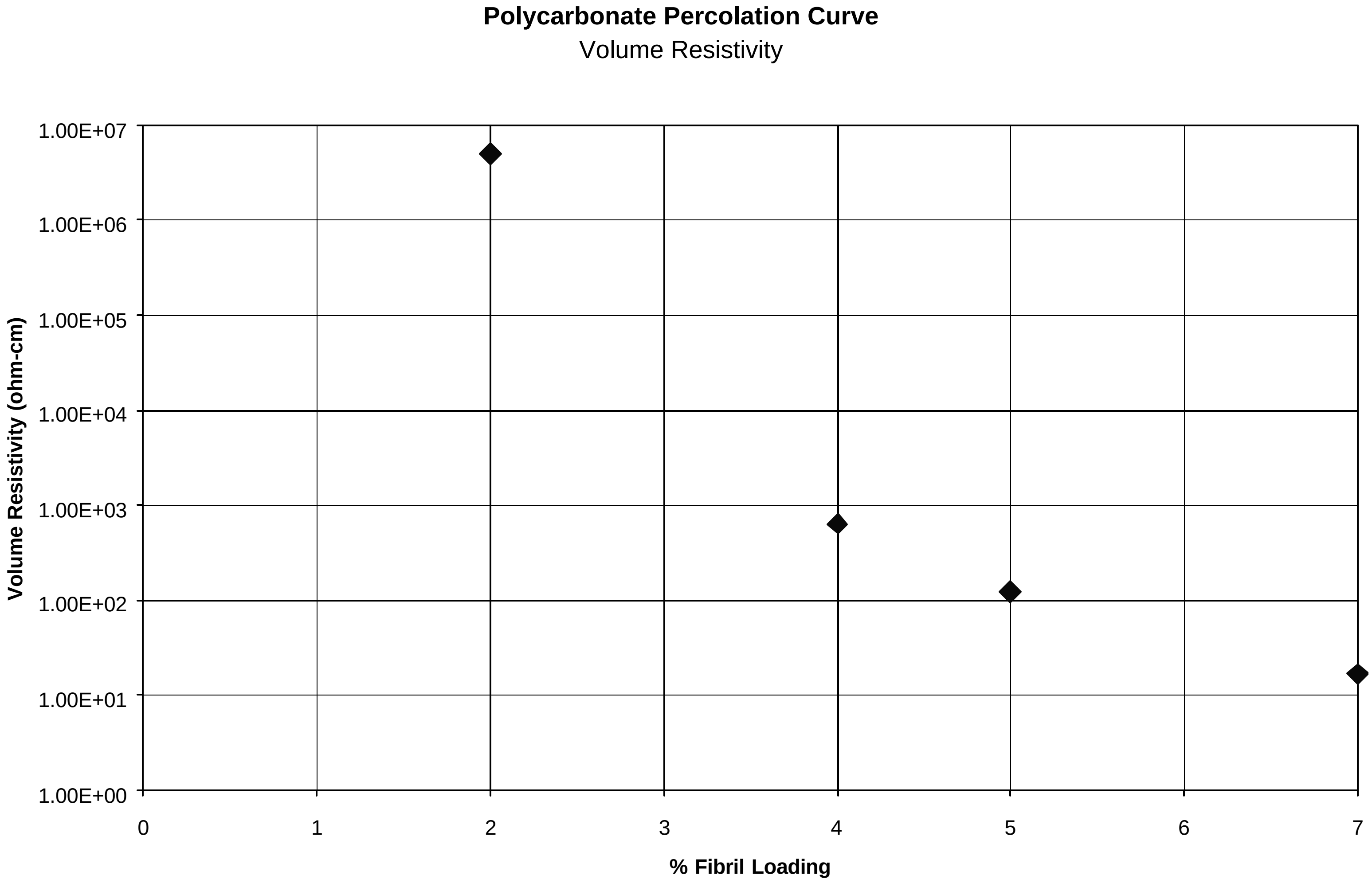
Nanotubes as Conductive Additive

2% in Polycarbonate Gives ESD Conductivity



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Conductive Additive Comparison

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}

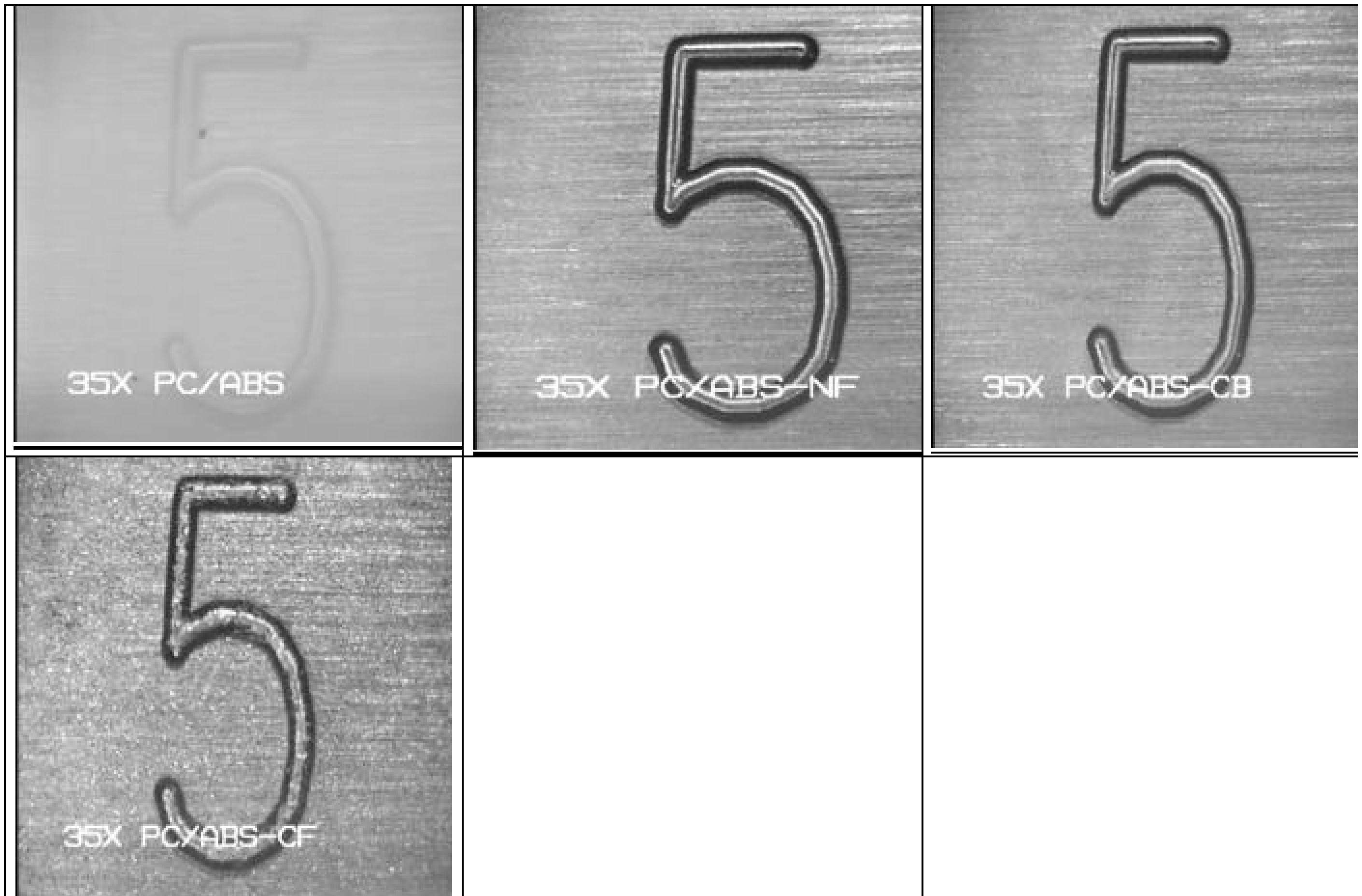
Additive Effect on Ductility

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

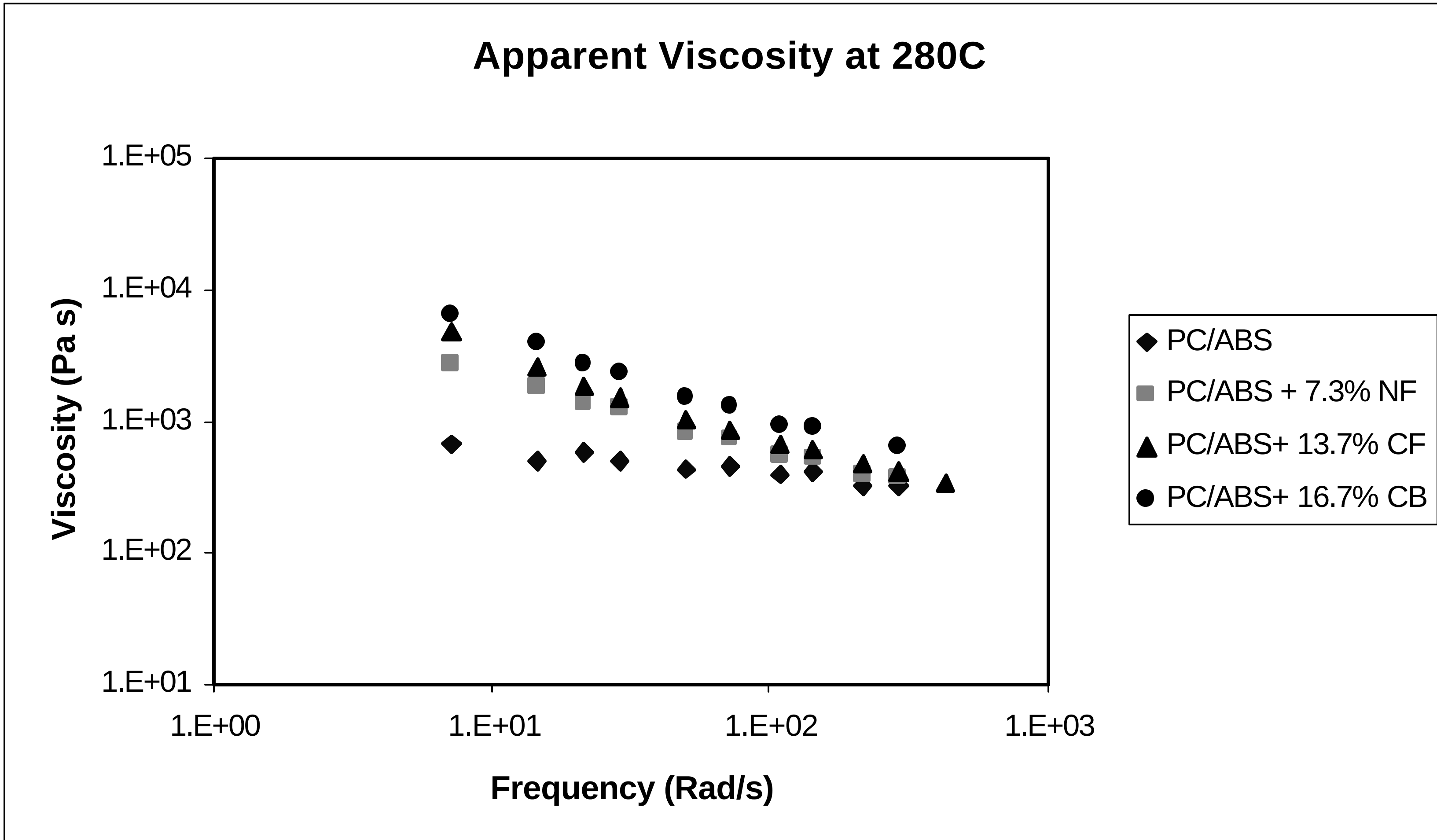
Additive Effect on Part Surface

Nanotubes Give Smoothest Part Surface



Additive Effect on Resin Viscosity

Nanotubes Have Least Effect on Viscosity



Nanotubes in Plastics

Summary of Resin Physical Properties Benefits

- Low loading
  - Preserves more of base resin properties such as toughness
  - Minimal effect on resin viscosity
- Small size
  - Excellent part surface quality
  - Highly isotropic distribution within part
- Lower risk of particle contamination
  - Less sloughing
  - Less abrasion
- Lower risk of vapor contamination
  - Less outgassing

FIBRIL Nanotubes in Plastics

Multiple conductive applications commercialized

Automotive

- Fuel Lines
- Painted Body Panels and Hardware

Electronics

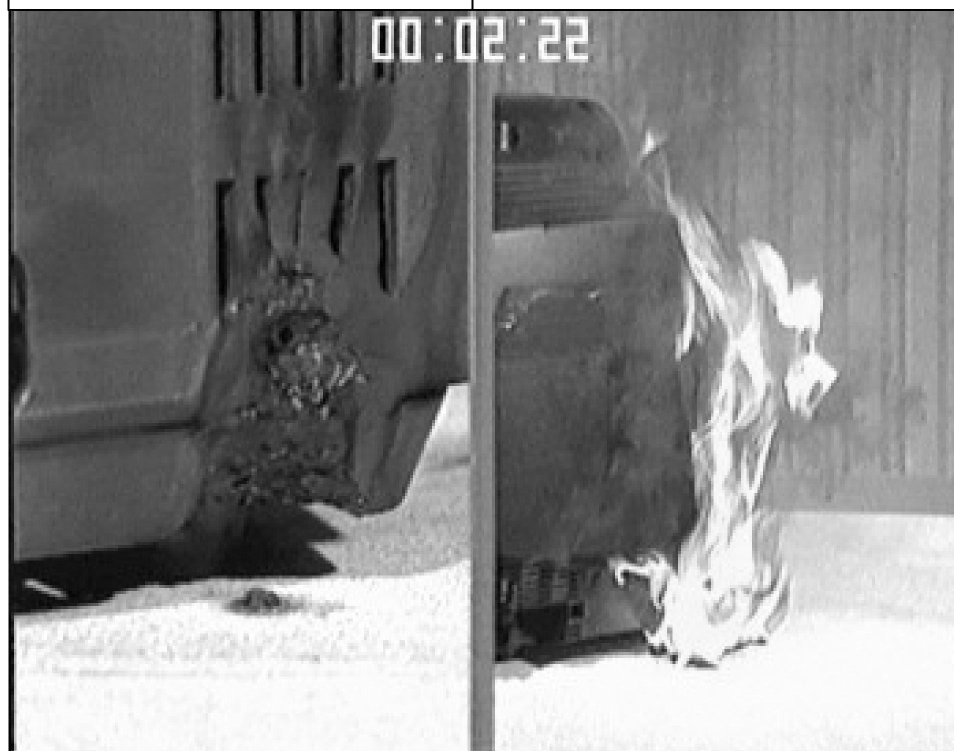
- Semiconductor Processing Equipment
- Hard Disc Drive Manufacturing
- Clean Room Equipment
- ESD Shipping Trays

Most Plastics Are Combustible

Multiple hazards from burning plastics

- Heat release
- Dense smoke
- Toxic gasses

flame retarded TV set	non-flame retarded TV set



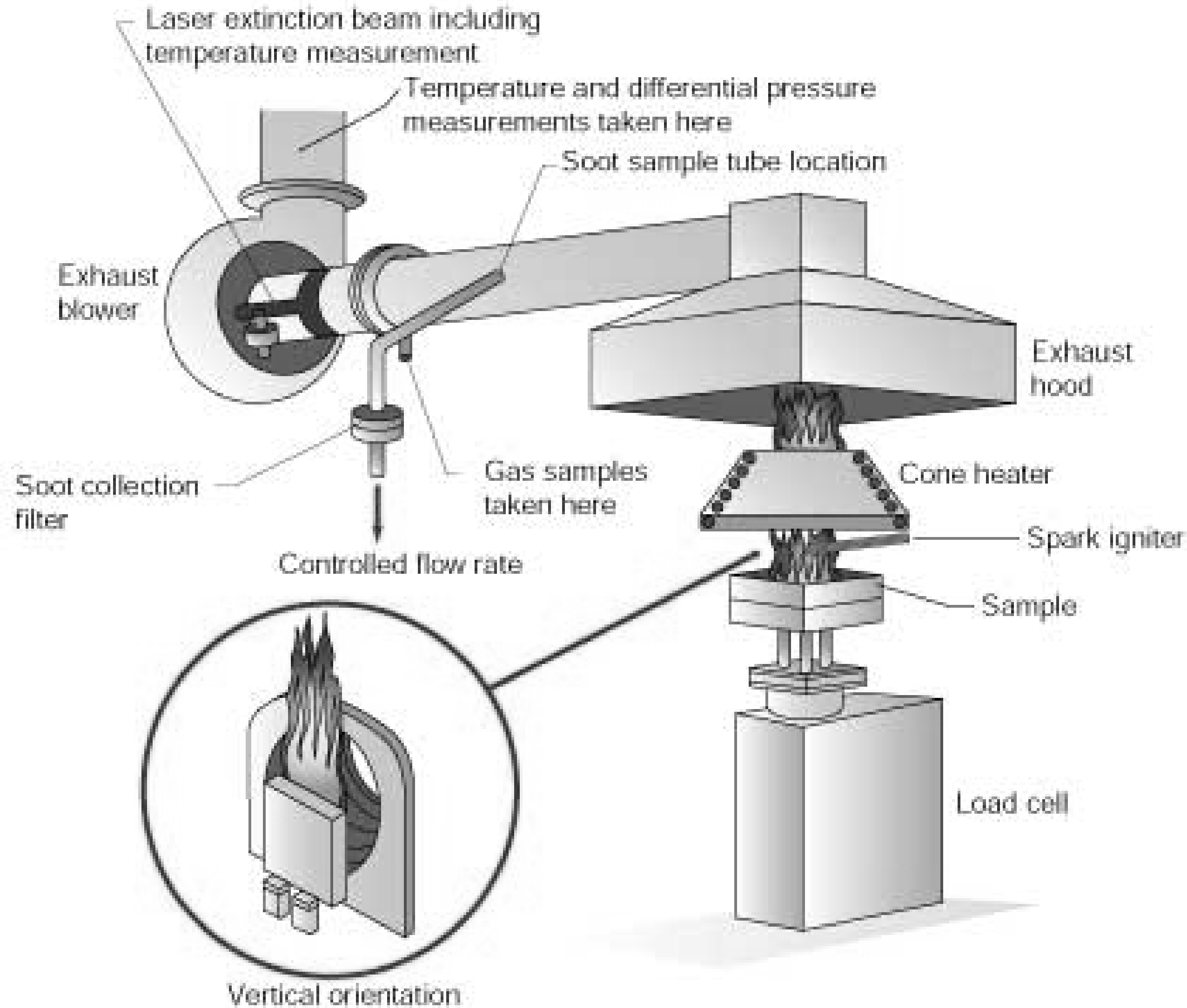
Several Types of Flame Retardants

- **Heat Absorbers**: decompose to liberate cooling water
- **Flame Quenchers**: interrupt chemical reactions in the flame
- **Synergists**: enhance performance of flame quenchers
- **Char Formers**: provide an insulating layer against heat and choke off fuel source
  - **Char Reinforcers**: preserve structural integrity of char

Measuring FR Performance

Cone calorimeters are widely used

Heat release rate is single most important variable in a fire and can be viewed as the driving force of the fire.



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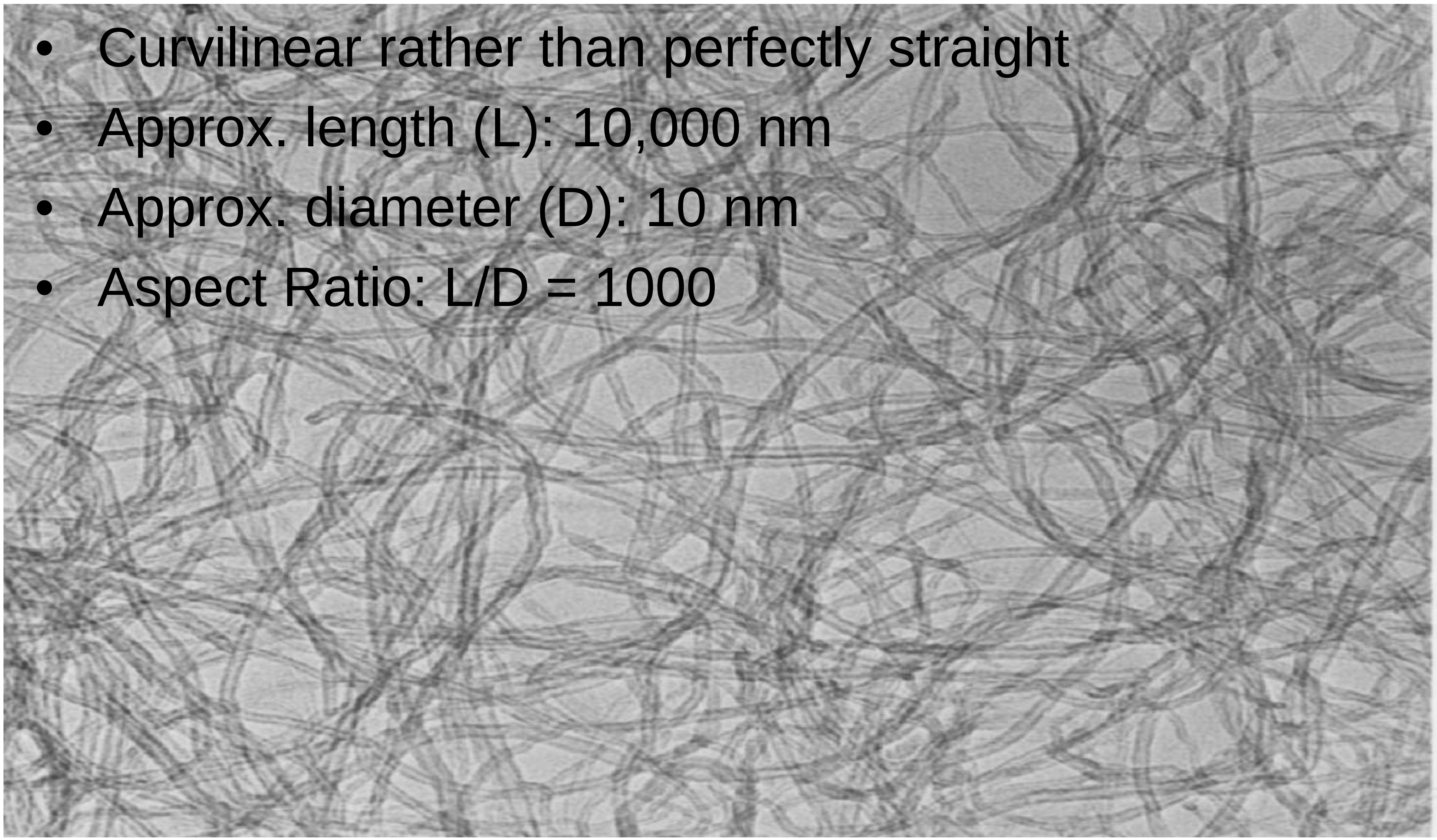

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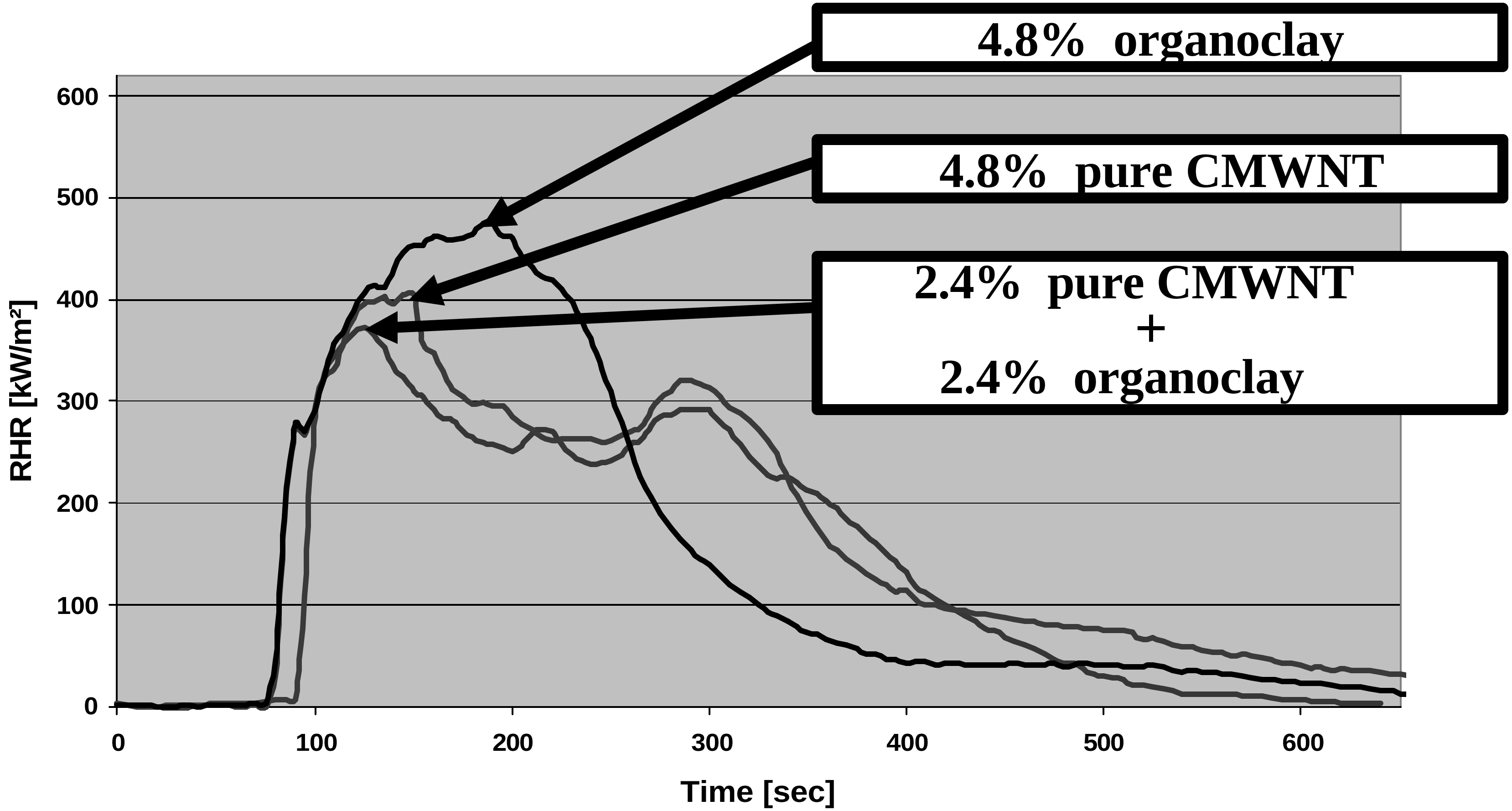
Nanotubes / Nanoclays in EVA

- Nanotubes lower peak heat release rate (PHRR) better then nanoclays
- Nanotubes + nanoclays synergistically reduce PHRR

CMWNT wt. %	Nanoclay wt. %	Peak Heat Release Rate kW/m^2
0	0	580
0	2.4	530
0	4.8	470
2.4	0	520
4.8	0	405
2.4	2.4	370

Beyer G., Fire and Materials, 2002; 26: 291-293

Nanotubes / Nanoclays in EVA



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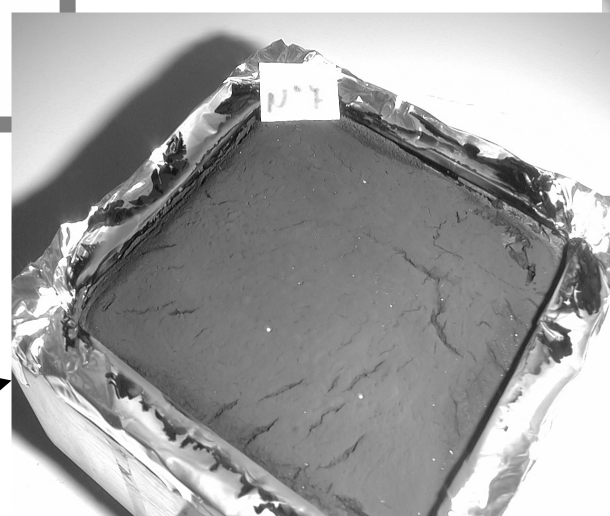
Nanotubes as an FR in EVA

Mechanism may be char reinforcement, especially in mixed system

4.8% nanotube

4.8% nanoclay



2.4% nanoclay
plus
2.4% nanotube

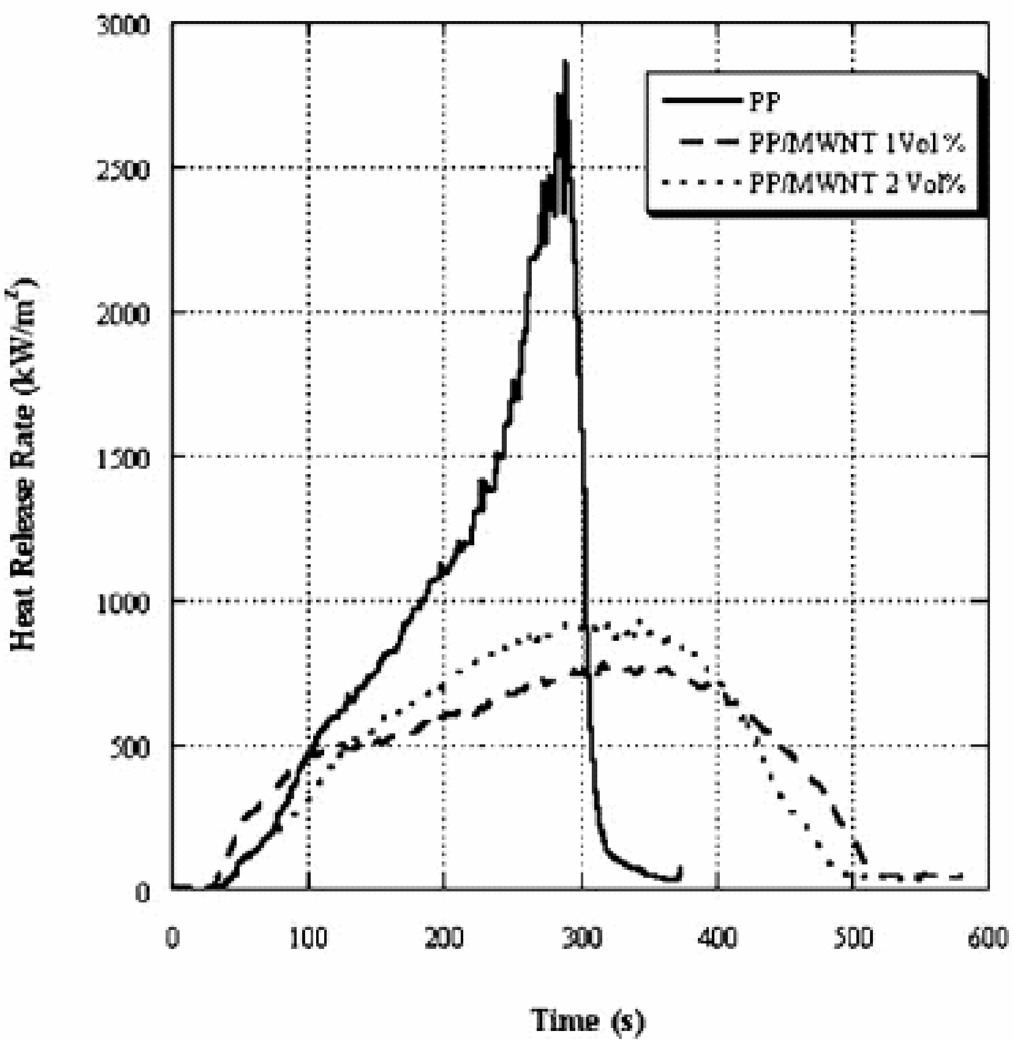
Beyer G., Fire and Materials, 2002; 26: 291-293

Nanotubes as an FR in PP

Peak heat release rate greatly reduced

Several possible reasons suggested, but exact mechanism not yet confirmed

- Iron in catalyst used to grow nanotubes may be acting as the FR
- Char reinforcement by nanotubes discounted in this resin



T. Kashiwagi, Macromol. Rapid Commun. 2002; 23, 761-765

CMWNT FR Benefit Overview

- **Non-Halogenated**
  - **Environmental improvement**
  - **Regulatory driven, especially in EU**
- **Low Loadings**
  - **Preserves base resin properties**
  - **Minimizes viscosity increase**
  - **Maintains flexibility, toughness**
  - **Preserves formulation versatility**
  - **FR possible with or without electrical conductivity**

FIBRIL Nanotubes as an FR in Plastics

EVA masterbatch let down into EVA and PE

- Peak Heat Release (PHR) rate reduced by FIBRIL nanotubes in both EVA and PE
- Nanoclays, and blends of nanoclays with FIBRIL nanotubes, work in polar EVA but not in non-polar PE

Beyer G., Presentation at 2003 BCC Conference on Flame Retardants

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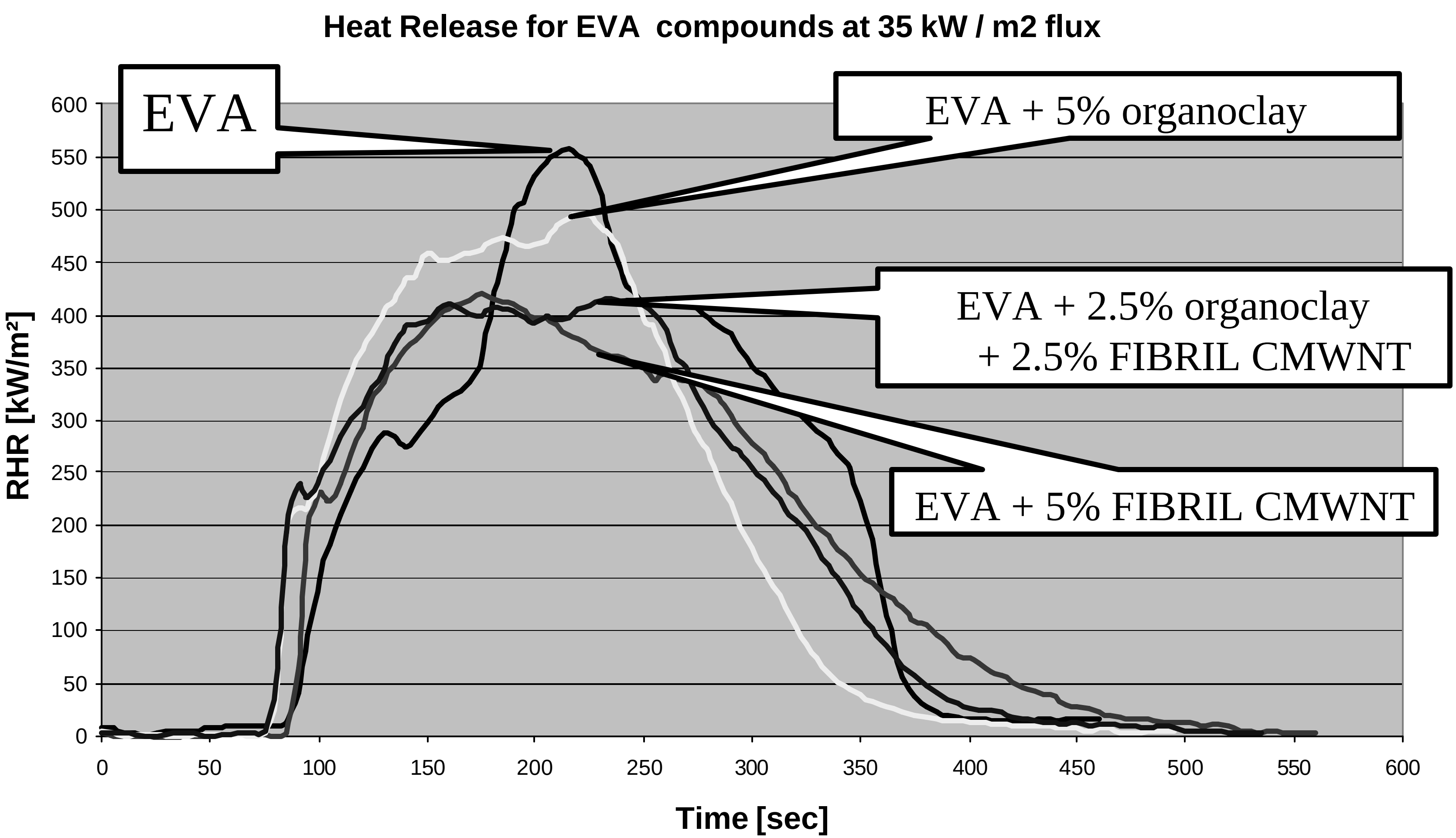
Hyperion EVA Masterbatch in EVA



Beyer G., Presentation at 2003 BCC Conference on Flame Retardants

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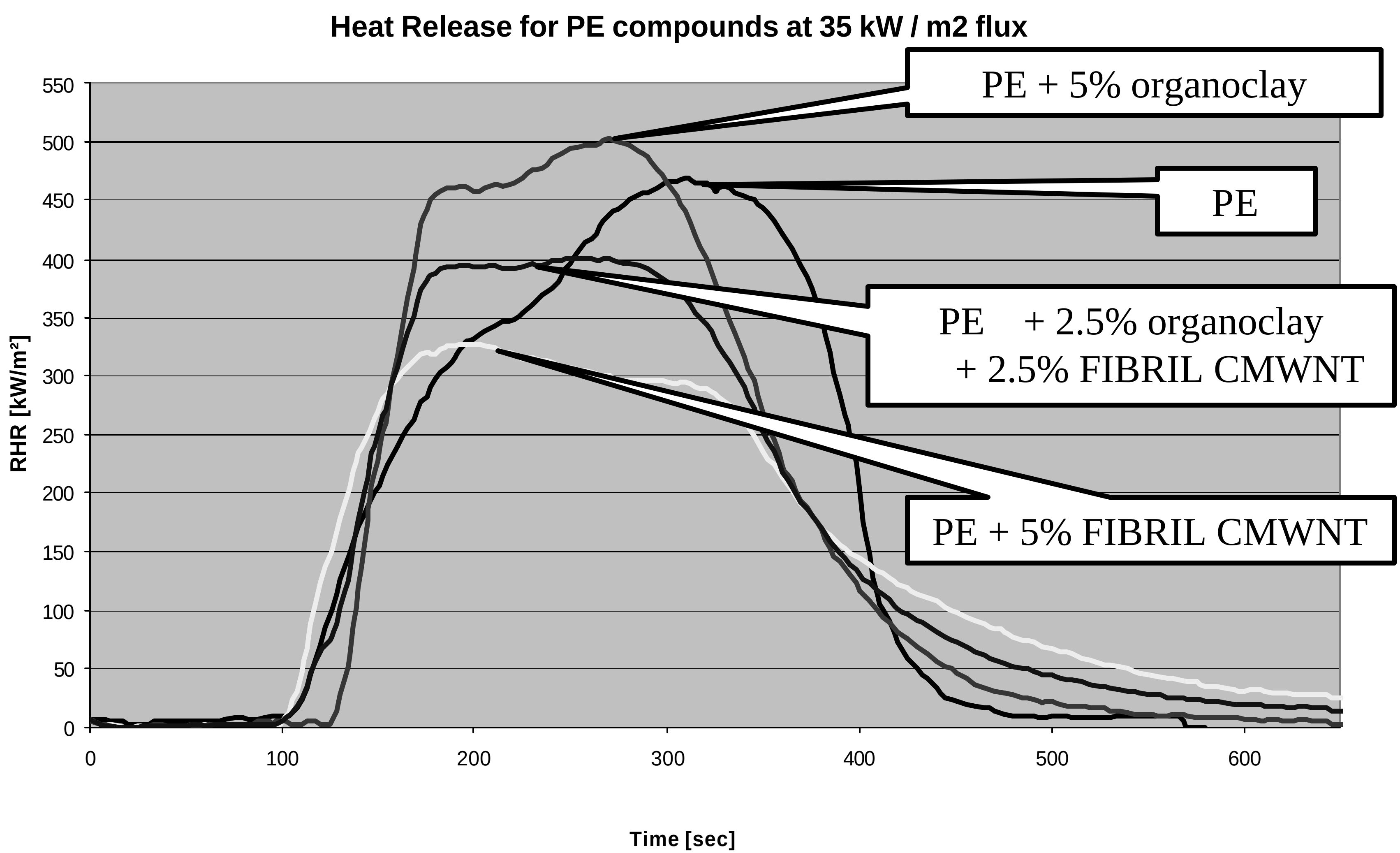
Hyperion EVA Masterbatch in PE



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