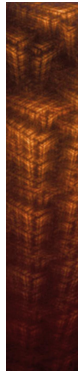


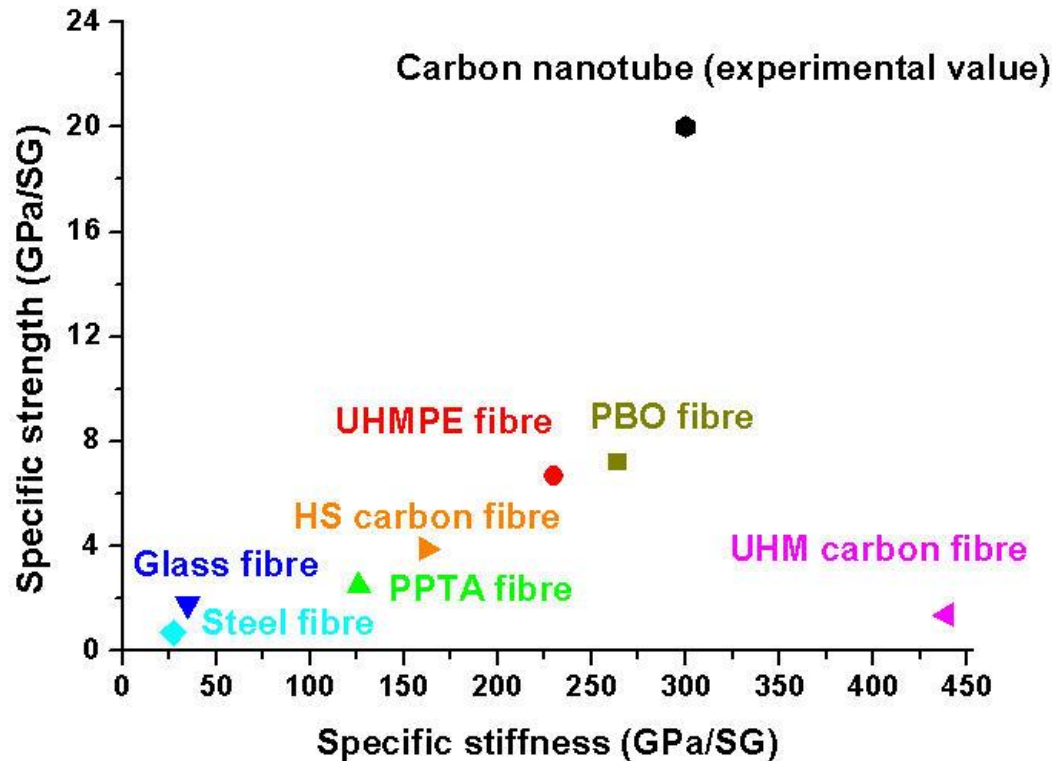
Multifunctional composites based on nanocarbons

www.materials.imdea.org



Graphene

Properties of high-performance materials and nanocarbons



Strength (Stiffness) / density



Other properties of carbon nanomaterials

Electrical conductivity $\sim 10^7$ S/m
similar to copper per unit mass

Thermal conductivity 1000 – 5000 W/mK
up to 5 times K1100

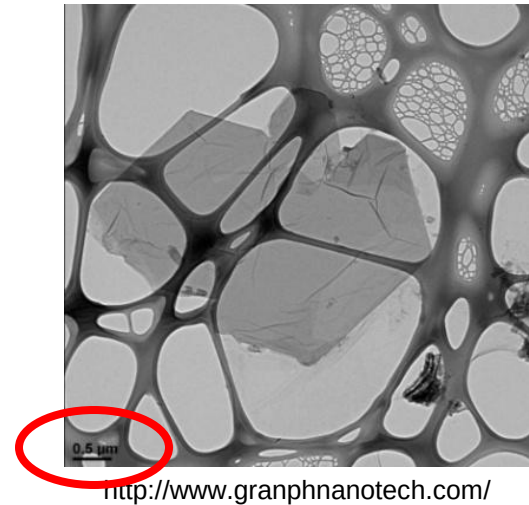
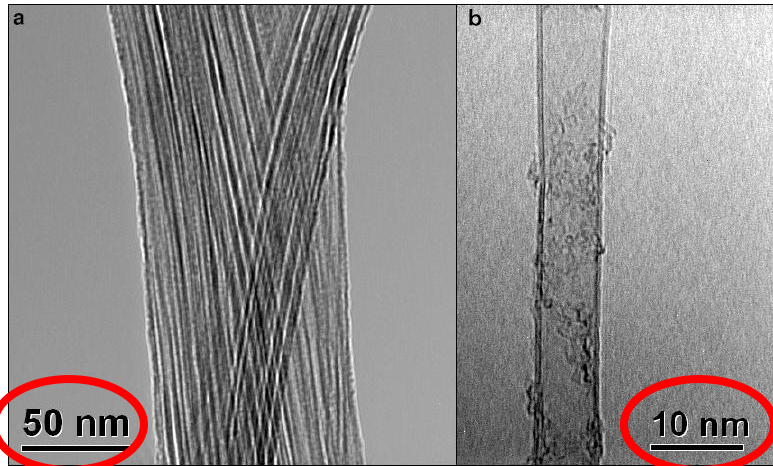
Surface area up to 2600 m²/g
10000 higher than
a typical CF (0.2 m²/g)

Properties in c-axis are about one thousand lower



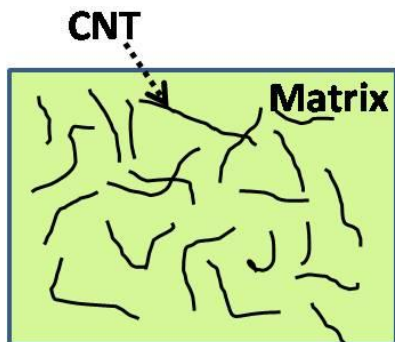
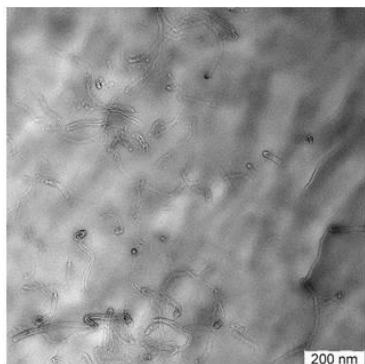
The Future - the ultimate material ?

Maybe the ultimate building block

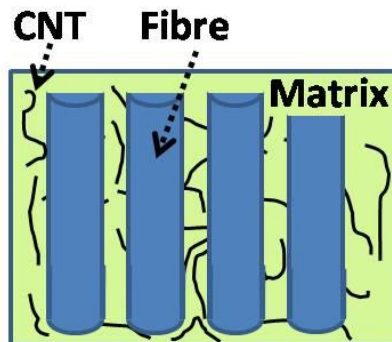
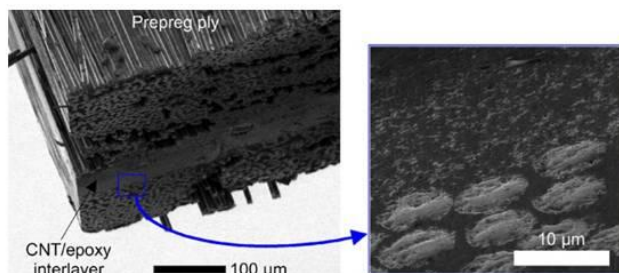


Composite integration routes

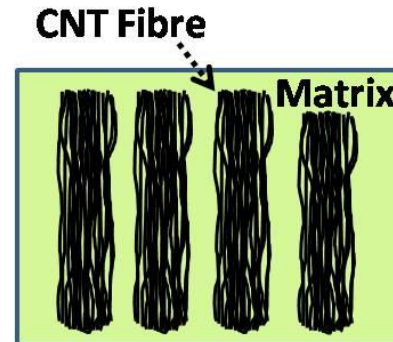
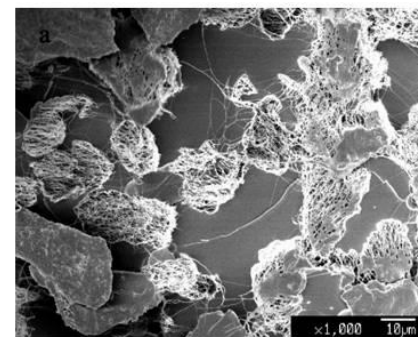
Filler



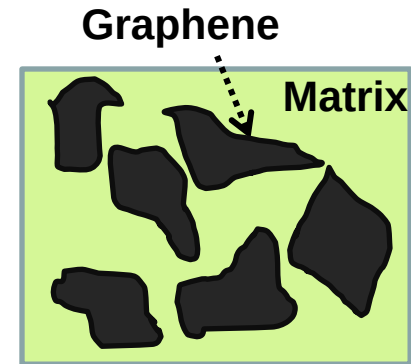
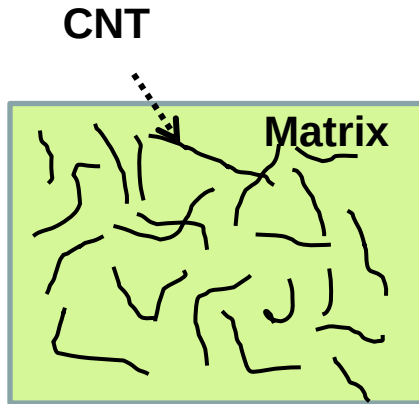
Hierarchical



Fibres

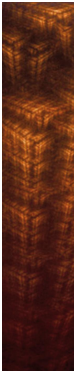


Nanocarbons as fillers

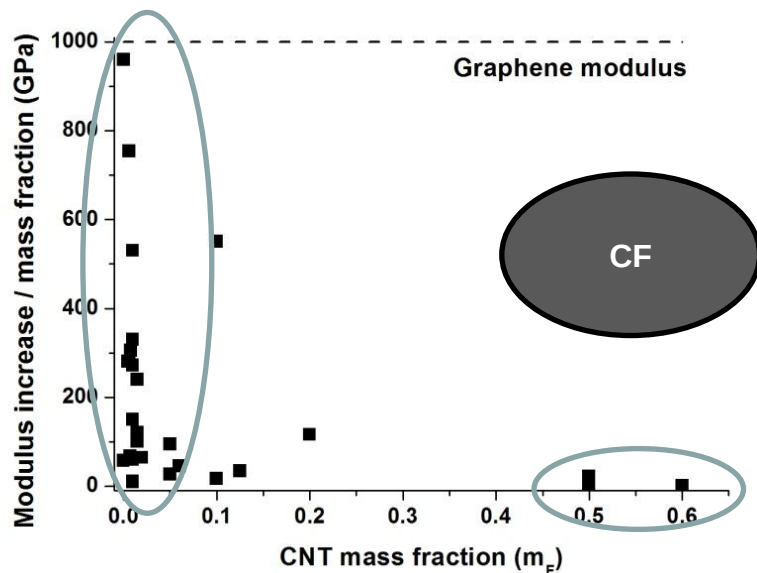


How to estimate the degree of reinforcement?

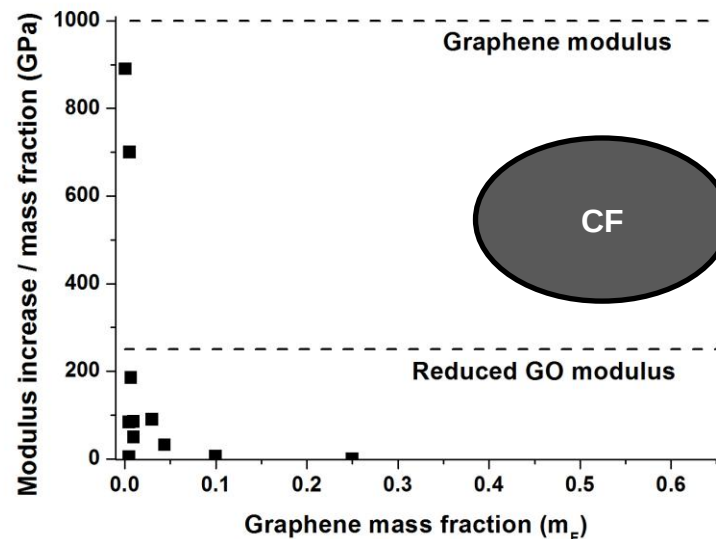
Increment in matrix modulus
mass fraction



Nanocarbons as fillers



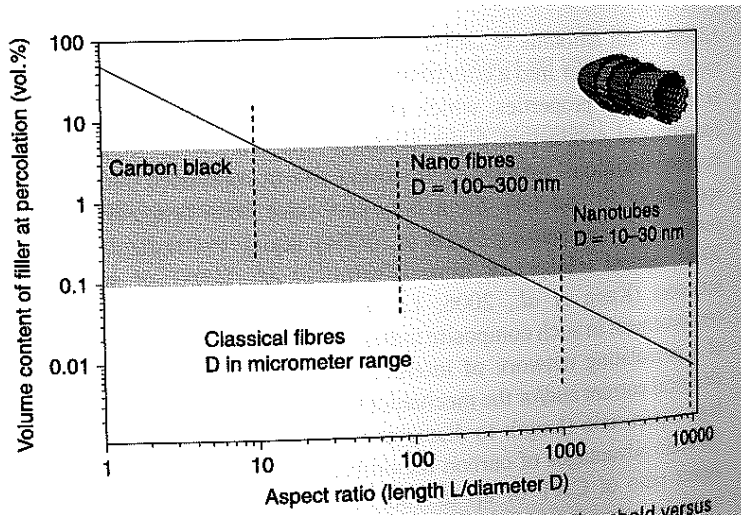
Data from 1994 – 2011 for CNT-polymer composites



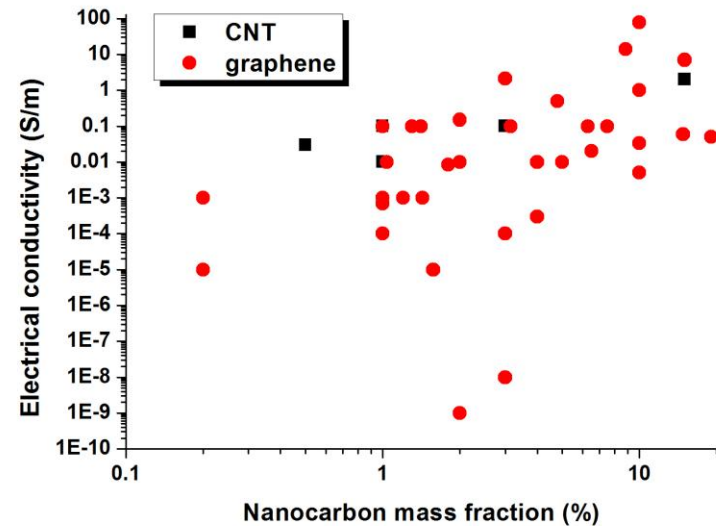
Graphene-polymer composites so far



Electrical properties



Alig et al. Polymer-carbon nanotube composites, 2011

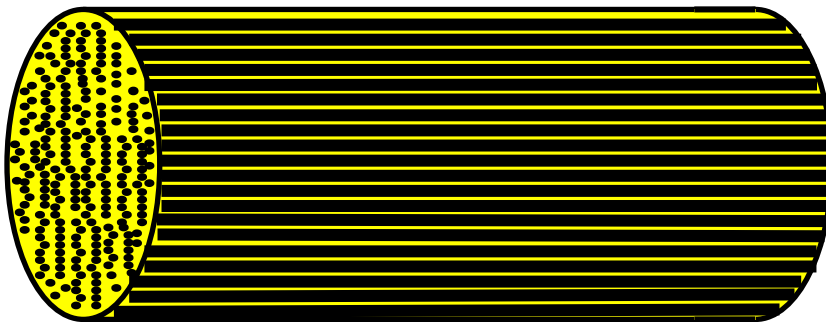
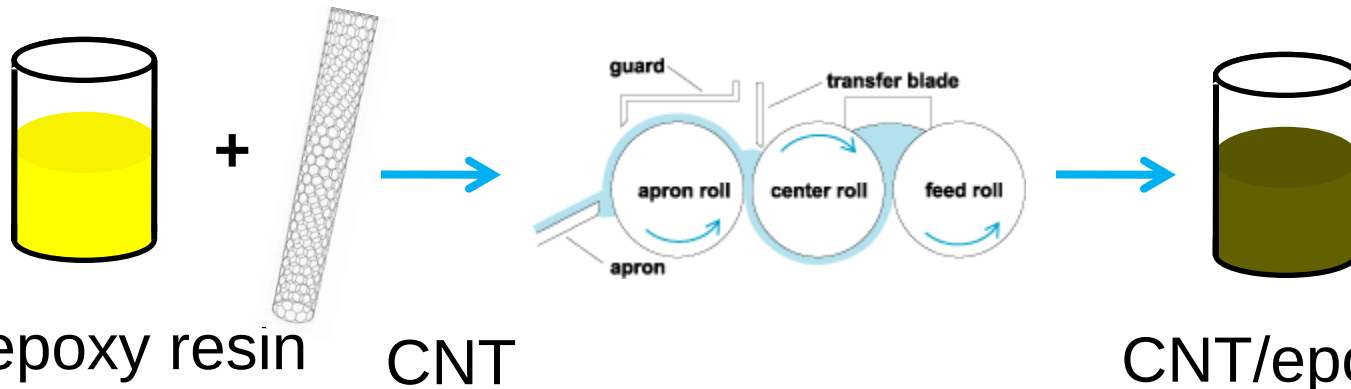


Base for other applications: EMI, damage sensing, de-icing, etc

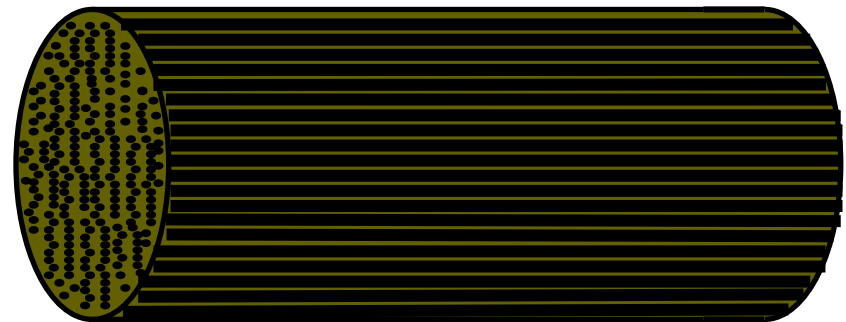


Some experimental results

Aim: improve properties of industrial CF composites adding CNTs



Standard CF/epoxy composite

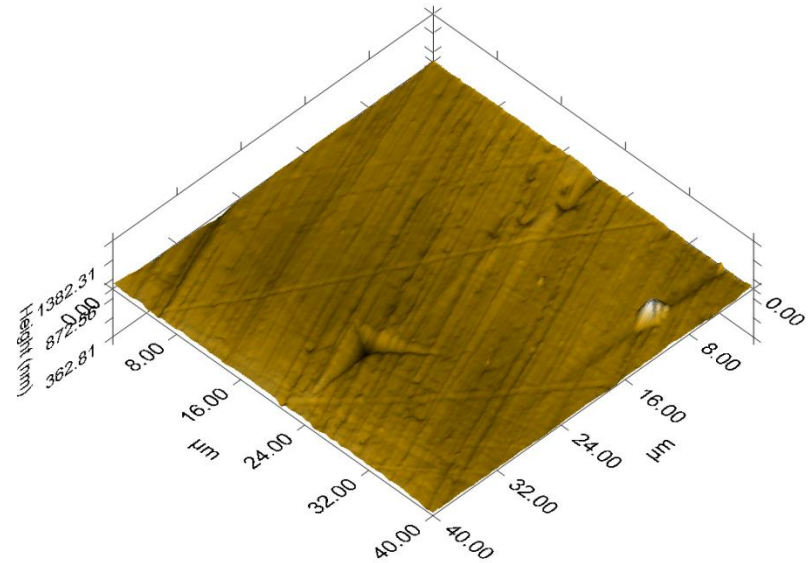
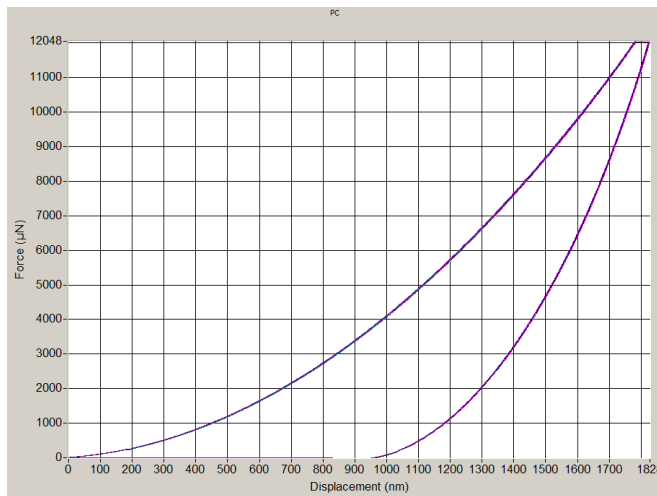


CF/epoxy composite with CNTs



Mechanical properties: nanoindentation

First, determine properties of CNT/epoxy system

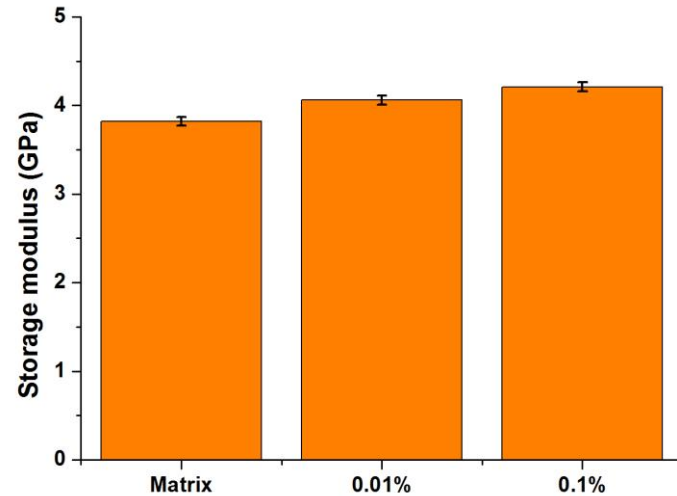
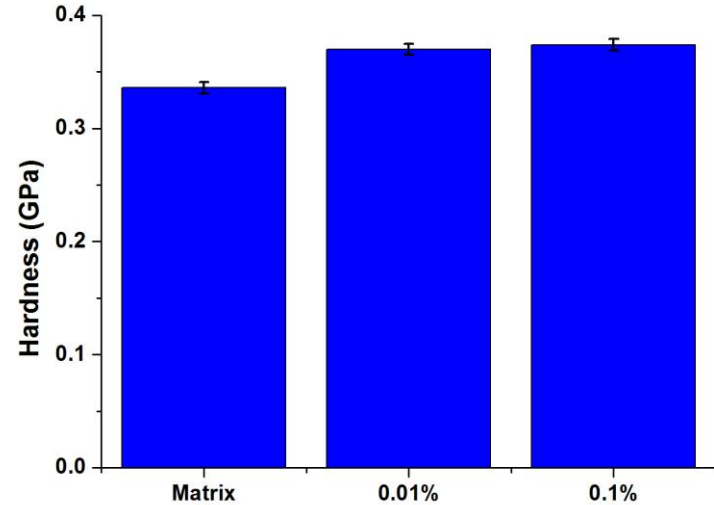
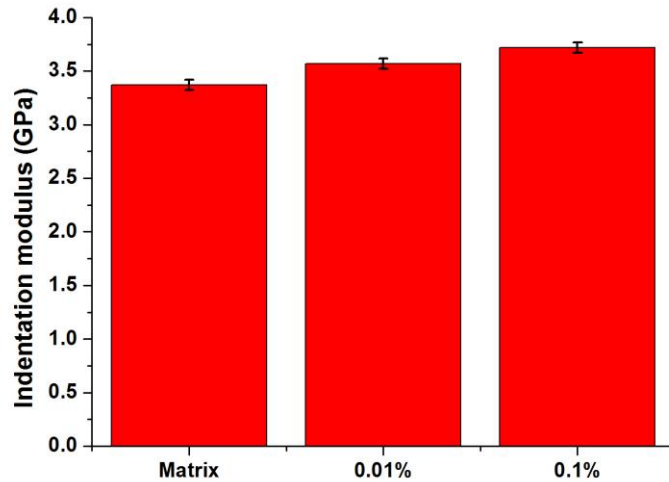


Both quasi-static test and nano-DMA

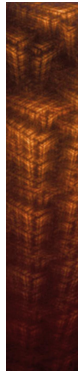
- Hysitron TI950 Indentation instrument
- Pyramidal (Berkovich) indenter ($R \sim 100$ nm)
- Constant Strain Rate of ~ 0.1 s $^{-1}$ during loading
- Variable force modulation during loading (5 – 30 μ N)
- Maximum Indentation Force = 12 mN
- Calibration check with reference samples (e.g. PC and PMMA)



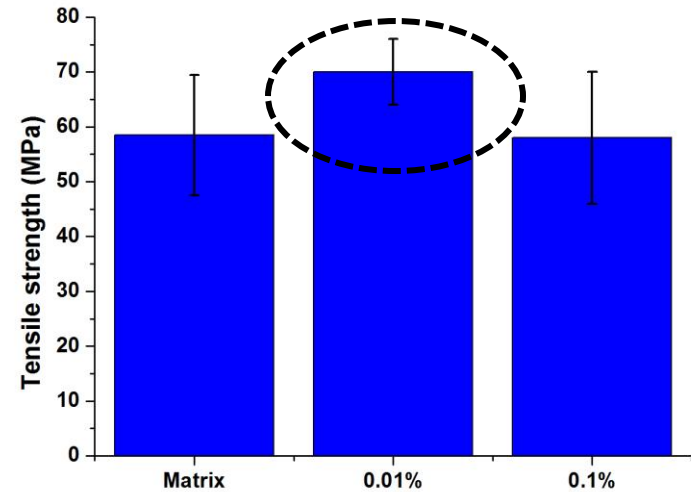
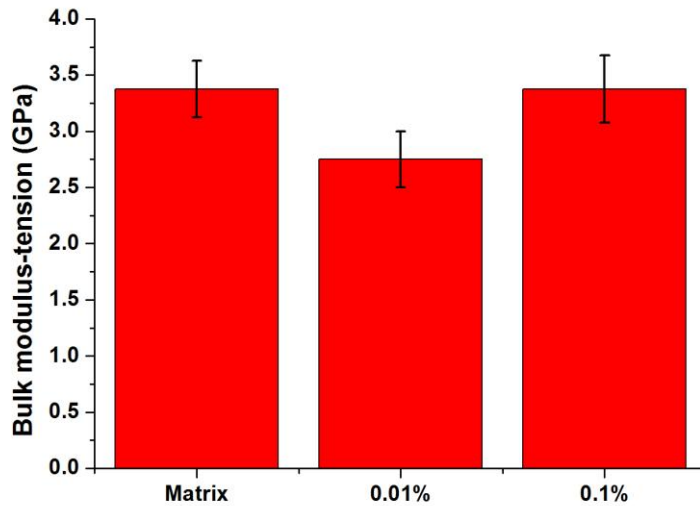
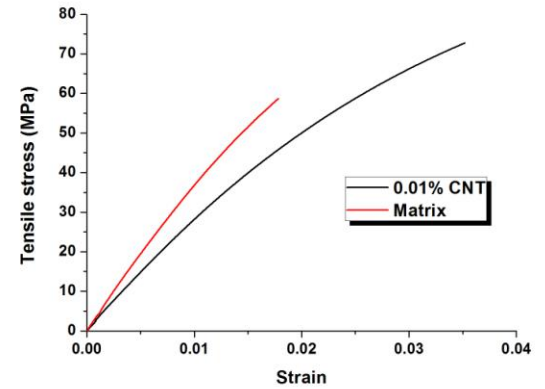
Mechanical properties: nanoindentation



No significant change in
tan delta with nano-DMA



Bulk properties



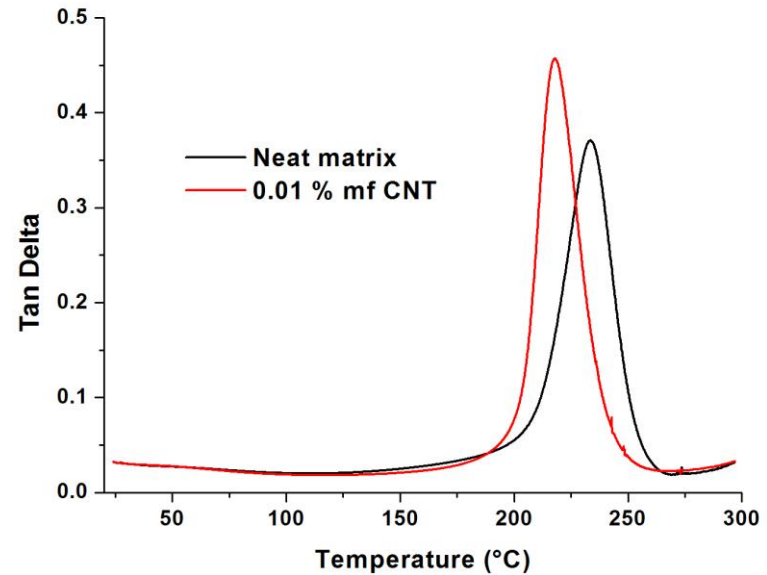
$$\frac{\text{CNT/matrix tensile strength} - \text{matrix tensile strength}}{\text{mass fraction}} = \frac{10\text{MPa}}{0.0001} = 100 \text{ GPa!}$$



Matrix effects

A)

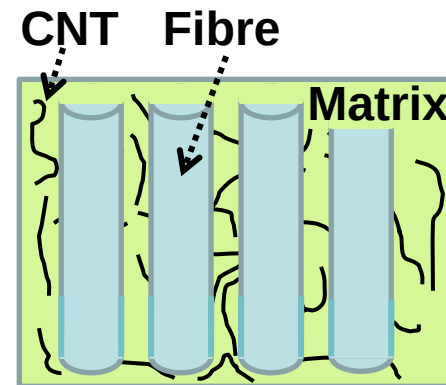
Matrix effects are very important at low mass fraction



B)

$$\text{Interface} \approx \frac{V_f}{\text{particle size}}$$

In a composite with 50% CF and 1% CNT, polymer-CNT interface is 100x larger





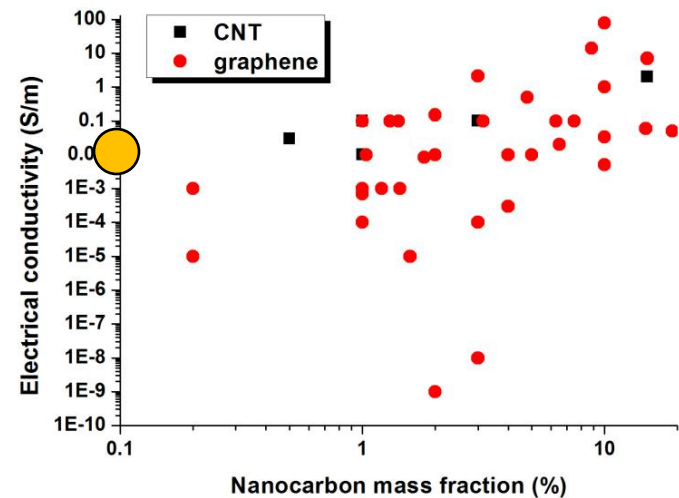
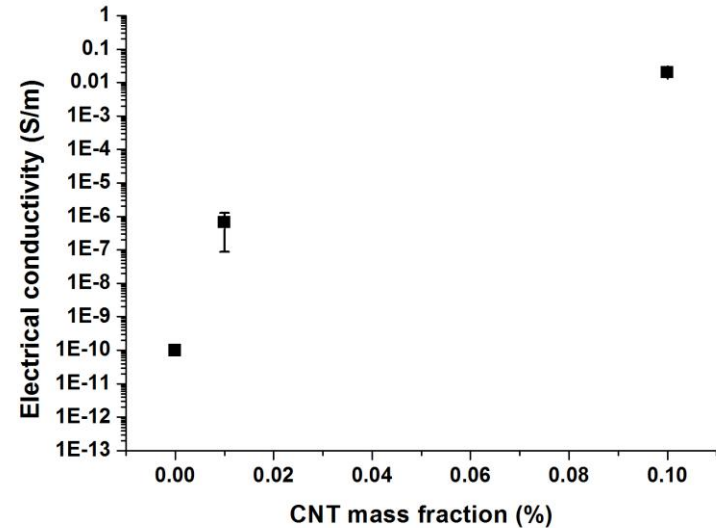
Electrical conductivity

Percolation around 0.01% mass fraction and conductivity of 0.02 S/m at 0.1%

The high purity, aspect ratio and number of walls of the tubes contribute to these results

Results above average

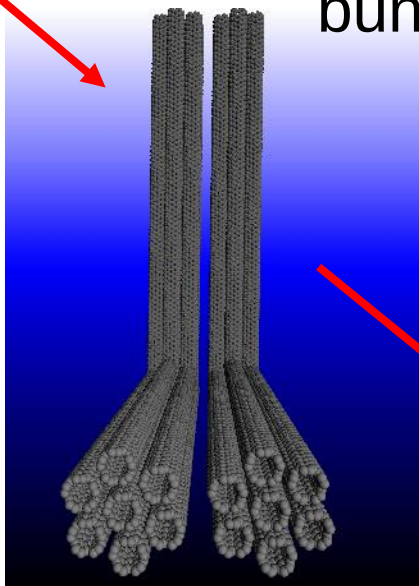
Sufficient to develop new functions in the composite



Third integration route: macroscopic fibre

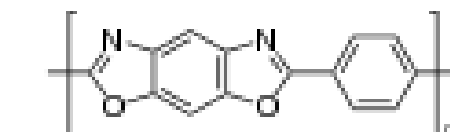
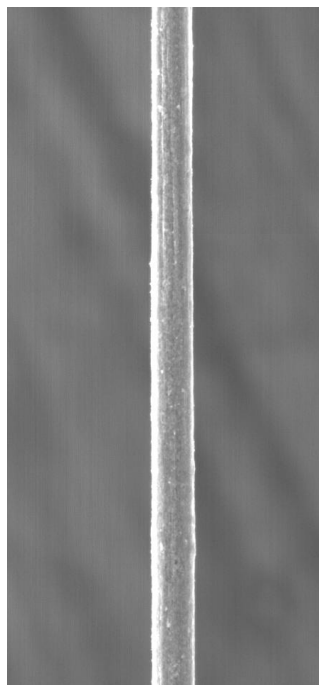


nanotube

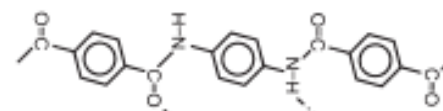


bundles

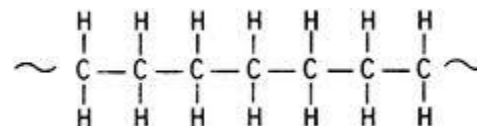
fibres, yarns



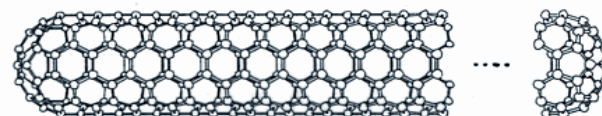
PBO (poly(p-phenylene benzobisoxazole))



Kevlar (poly(p-phenylene terephthalamide))



Dyneema – Spectra (polyethylene)

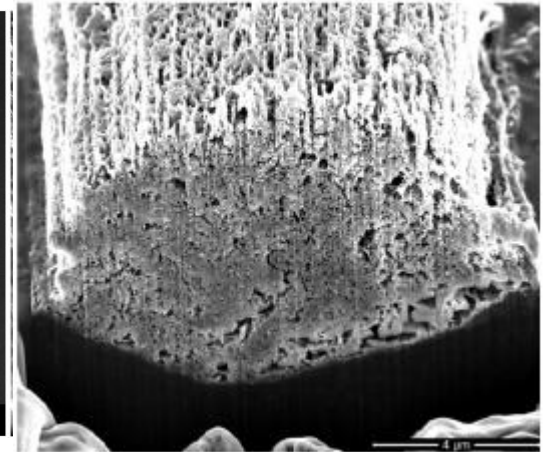
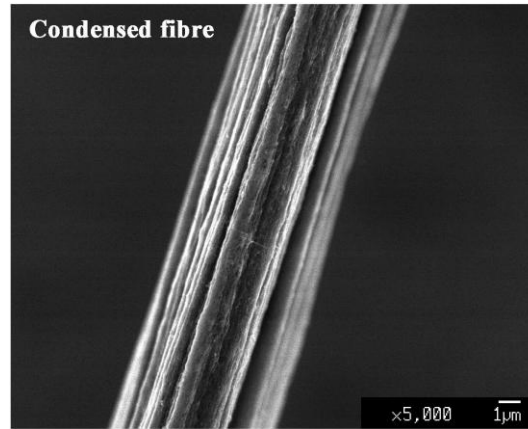
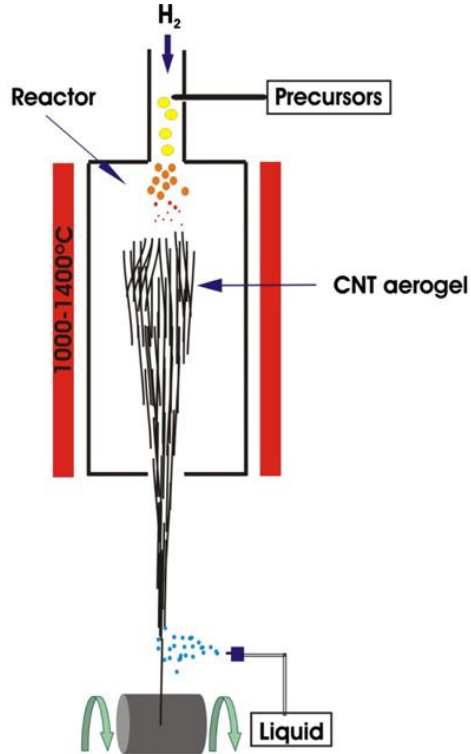


Proposed eighty years ago
(Wallace, JACS, 54,1269-1706 (1932))

ropes, cables



Third integration route



Continuous one stage process

Spinning rate >100 m/min

Macroscopic material entirely
made up of nanobuilding blocks

Currently under industrial scale-up



Direct spinning of CNT fibre

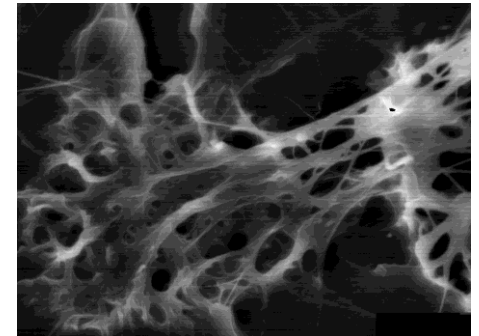




Fibre properties

Physical:	Density	0.5 – 1.1 g/cc
Mechanical:	Strength Stiffness	1.0 – 3.5 GPa/SG 40 – 100 GPa/SG
Thermal:	Conductivity	150 – 1000 Wm ⁻¹ K ⁻¹
Electrical:	Conductivity	1x 10 ⁶ S/m
Surface area:		200m ² /g

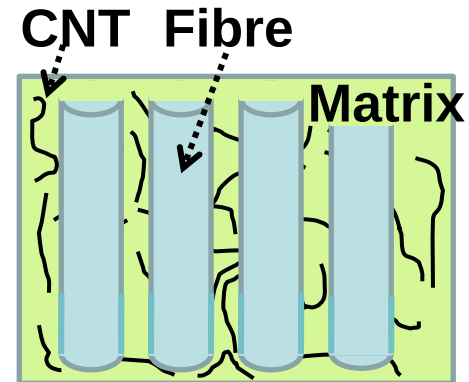
Superb composite integration



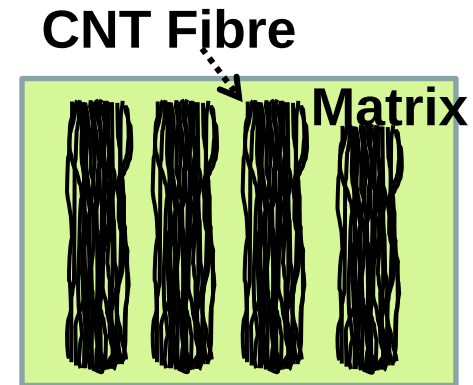


Opportunities for multifunctional materials

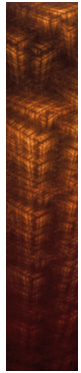
Hierarchical composites: fatigue, barrier properties and conductivity. (using small amounts of filler)



Nanostructured fibres: surface area, multifunctional properties, chemical and thermal stability



Acknowledgements



institute
imdea
materials

www.materials.imdea.org

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Miguel Monclús
Jon Molina



Thank you