NT'06 POSTER SESSION E

- IX: NANOTUBE-BASED COMPOSITES (50 abstracts)

VERY MESSY TOPIC

- XII: THERMAL AND MECHANICAL PROPERTIES OF NANOTUBES (14)

CLEAN AND ELEGANT

IF DONE ON INDIVIDUAL TUBES

"COMPOSITES" posters fall into 3 different categories:

A. **Add** filler (SWNT, MWNT, VGCF….) to a matrix (polymer, metal, other carbon,) by (coagulation, melt mixing, co-extrusion, infiltration, ….)
B. **Dissolve** or suspend CNT or VGCF in a liquid. (here the goal is solubility rather than a solid with enhanced properties)
C. **Grow** some nano-carbon on some other carbon.

with or without the aid of an external field (magnetic, electric AC or DC, flow, strain) to induce alignment of the filler and/or the matrix.

POSTERS ON SOLID COMPOSITES

FILLERS

VGCF:	14
MWNT:	13
SWNT:	14

MATRICES:

POLYMER:	25
METAL:	4
CERAMIC:	2
OTHER CARBON	7

ALIGNMENT CONSIDERED	10
SOME or ALL "THEORY"	4

WHAT’S MISSING?

Resistance vs. temperature of CNT/polymer composites – identify conduction mechanism(s), understand and optimize electrical transport above threshold.

Texture/dimensionality of composite films – with no external field, the CNT alignment will be random in the film plane. On the other hand, all deposition processes guarantee a preference for CNT to lie parallel to the substrate.   This happens to varying degrees depending on concentration in the dope, aspect ratio, growth rate etc.*, and needs to be quantified to understand the fundamentals of percolation thresholds, critical behavior etc.

Appl. Phys. Letters* **84, 2172 (2004)

It has long been appreciated that success in CNT composites requires

1. uniformity of CNT dispersion in the matrix,
2. control of CNT alignment, and
3. interfacial "adhesion" in the context of mechanical, electrical and thermal "load transfers".

1 and 2 largely solved; 3 resists all efforts so far. Why?

FUNCTIONALIZATION throws out the baby with the bathwater; intrinsic CNT properties compromised by attachment points.

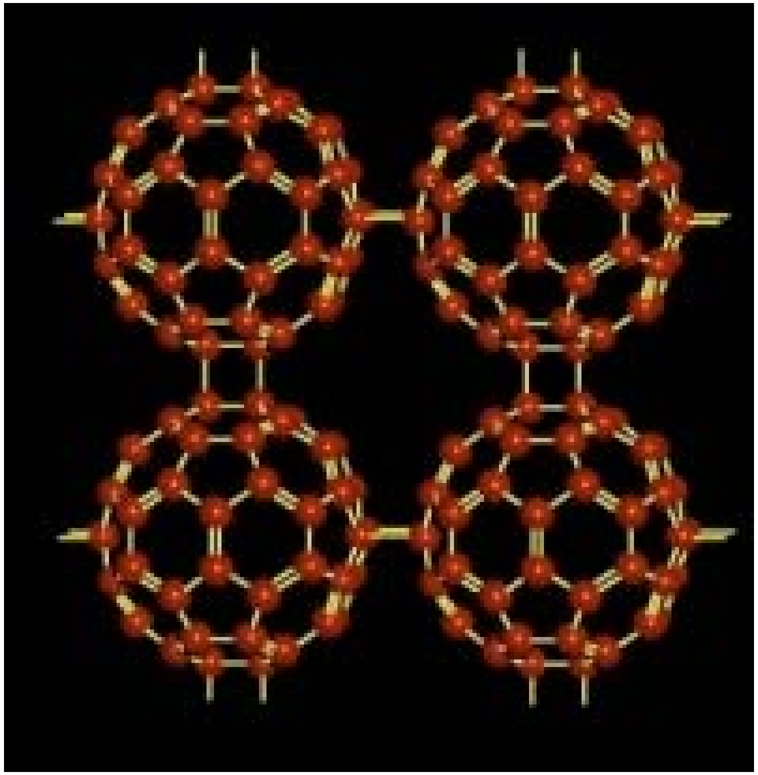
"PHONONS" IN GLASSY POLYMERS – how to get coherent phase and amplitude matching across the CNT/matrix interface with the lattice modes of the crystalline CNT?

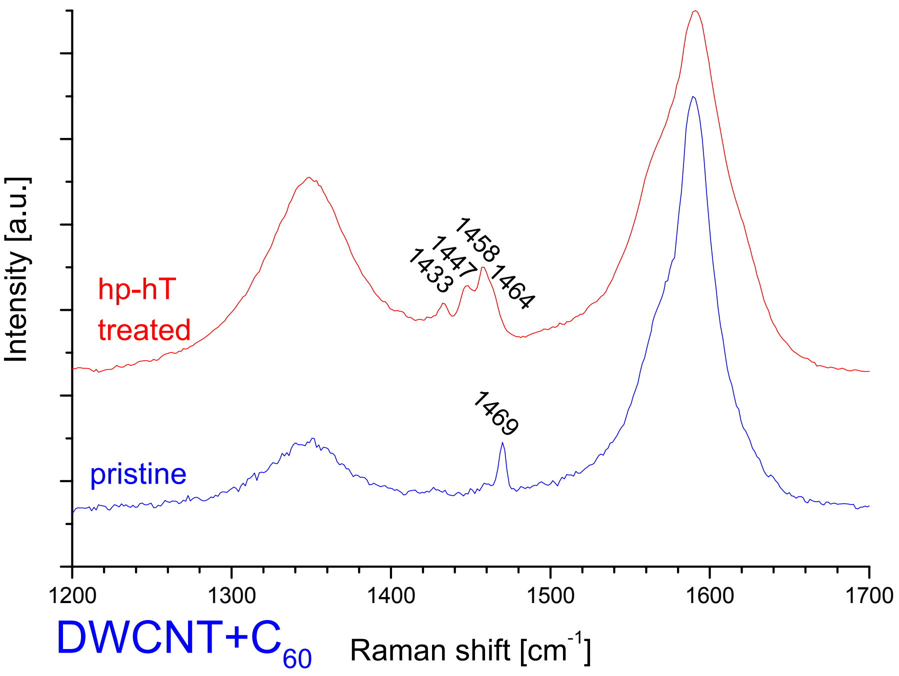
Some results are promising (Windle NT'99, Wagner, others) but haven't been realized *en masse*.

CNT loading limited by dispersion, viscosity (and price), so prepreg infiltration techniques (in particular surface treatments) perfected for graphite fiber composites can't be applied to CNT composites.

E001: mag field aligned VGCF in "polymer" – 1 wt% aligned with 10 Tesla gives huge resistivity anisotropy (Rice/Penn collaboration using 26T on 100% SWNT got $\rho_{parallel}/\rho_{perp} < 10$).

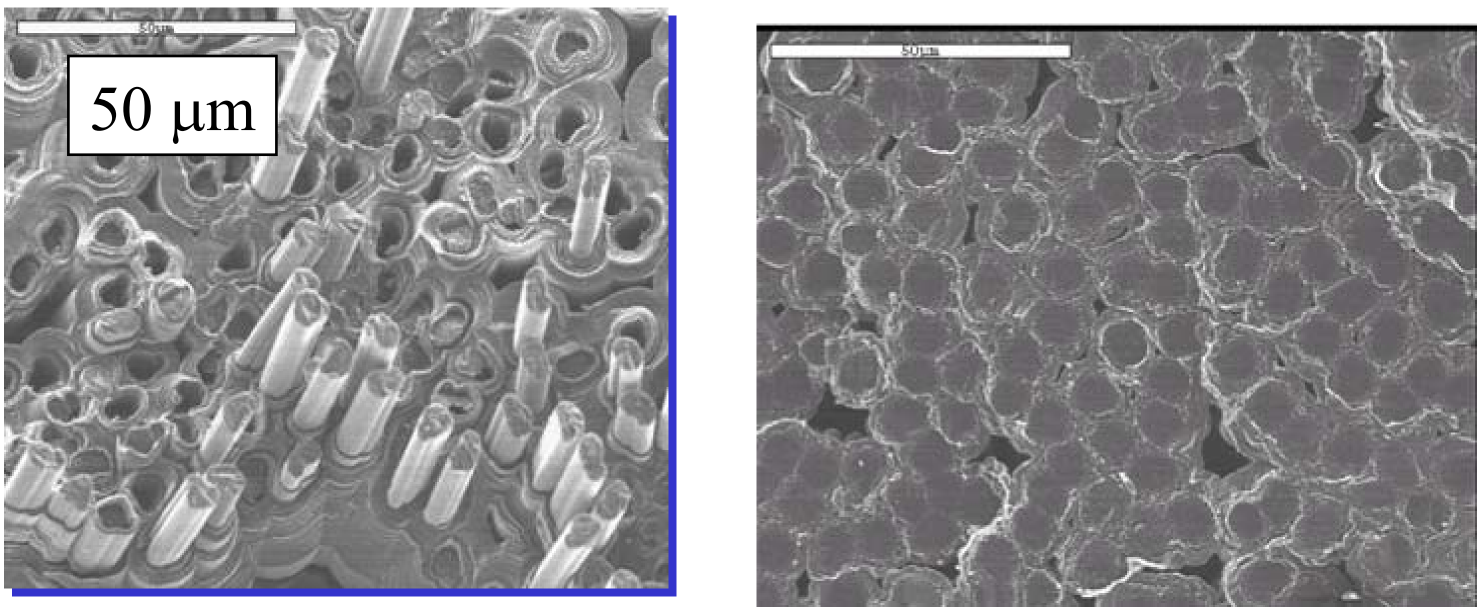
E008: high pressure synthesis of (SWNT, DWNT, MWNT) + C_{60} for superhard materials.





E009: 1 wt% MWNT in duralumin for improved strength – the authors use an "original mechanical mixing" technique which overcomes problems with dispersion and wettability.

E010: CNT grown directly on carbon fabric made from ex-PAN fibers, followed by CVD infiltration to increase the density. Improved mechanical and tribological properties expected.



C/C composite fracture surfaces after tensile strength tests

no nanotubes   with nanotubes

E013: From C/C to C/C/C composite: Grow CNF's on carbon cloth or felt, then infiltrate with a resin and pyrolyze – small weight penalty should give large enhancement in load transfer.

E012: Molded CNF/PC composites; finite element analysis to optimize the process. Use twin screw extruder to achieve homogeneous melt mix.

E014/015: CNT additives for conductivity enhancement:

100 μm diameter PVC spheres – 10^7-fold increase

electrospun fibers (silk, PEO) $\sigma \sim 10^{-4}$ S/cm

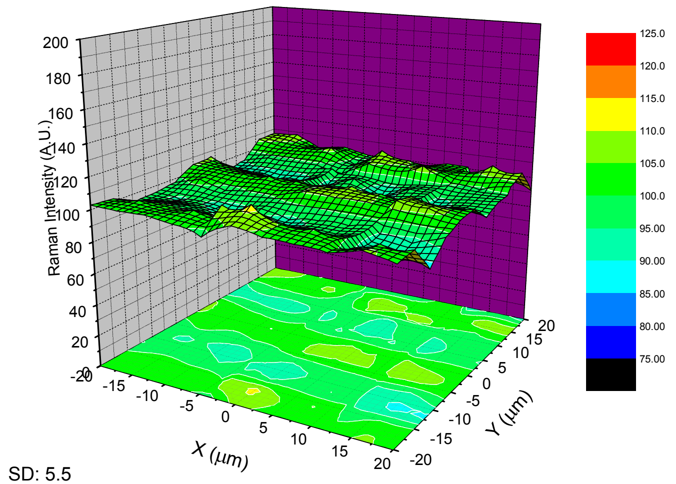
E019: Tribological properties of binder-free "SWNT solids" – ball-on-plate test shows evidence for material transfer in the form of a "colored tribofilm" – possibly interference fringes from semitransparent SWNT membrane?

E021: MWNT/polymer composites – does the polarity of the polymer influence the filler/matrix adhesion? Examine fracture surfaces using different polymer matrices.

E023: Coat SWNT bundles with polymer precursor to SiC and pyrolyze for better load transfer. If it works, lots of polymer precursor ceramics can be tried on this unsolved problem.

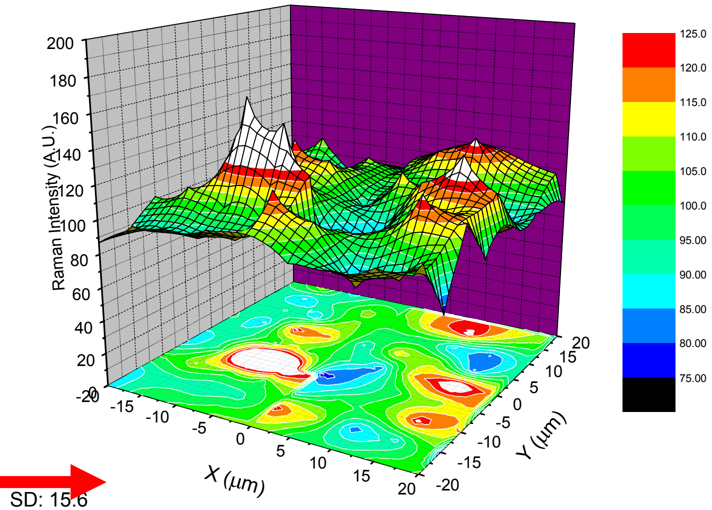
E024: Quality of CNT/polymer dispersion - examined here on many length scales using optical/SEM/TEM microscopy.

Microfocus Raman mapping also useful on 0.1-1 µm scale:

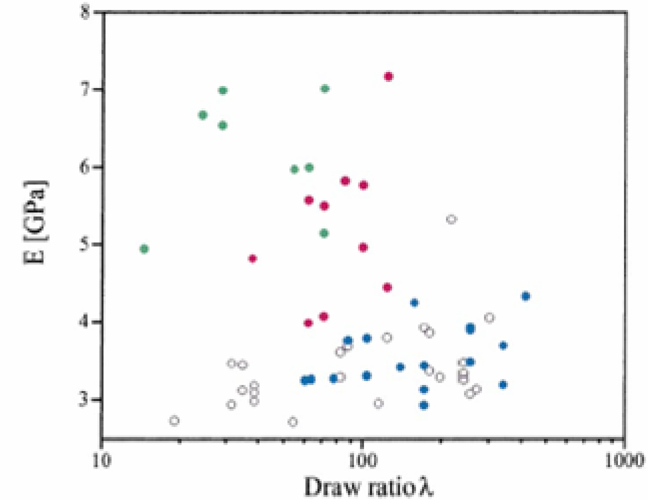


7wt% SWNT/PMMA: STD. DEV. 5.5%. twin screw extruder

1% SWNT/nylon: STD. DEV. 16% in situ polymerization



E025: Vertically aligned SWNT forest, infiltrated with MMA and polymerized *in situ*. How does this approach compare with melt-mixed SWNT/PMMA drawn into fibers, in which the alignment was excellent but the mechanical properties weren't? CPL **330**, 219 (2000).



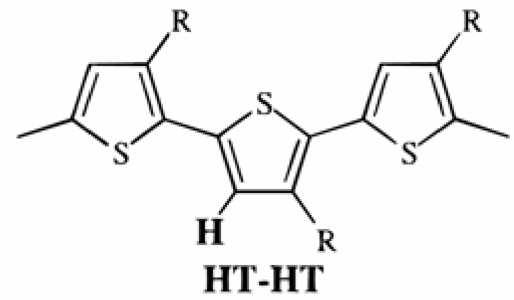
0, 1, 5 and 8 wt%

E028: Semitransparent electrode I – CNT/polyethylene composite film is transparent and conducting.

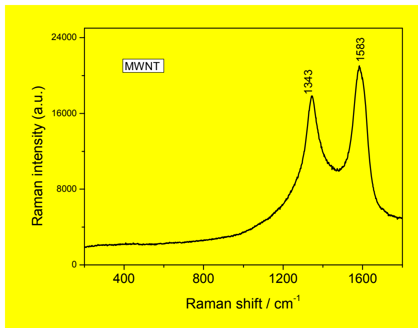
E029: Semitransparent electrode II – functionalized SWNT/PMMA film – 0.1wt% gives 92% transmission and $\rho \sim 10^{-3}\ \Omega$cm.

E030: Semitransparent electrode III – MWNT + organic-inorganic hybrid matrix, spin-coated on glass and plastic substrates – low temperature process.

E031: MWNT in poly(3-hexylthiophene)



P3HT/chloroform + MWNT/chloroform
↓
Sonication
↓
Precipitation in methanol



DC 2 point conductivity at room temperature:

P3HT (neutral) : ~10^{-10} S /cm

P3HT/MWNT (1 wt%): 1.7 10^{-3} S/cm

E034: MWNT/PC composite – percolation threshold 3-5%, seems high compared to literature. Alignment not specified – see next.

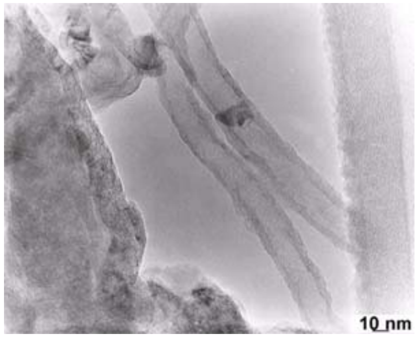
E038: SWNT/PMMA composite – percolation threshold depends on degree of alignment; the better the alignment, the higher the threshold concentration (logical). BUT the highest conductivity above threshold does NOT correspond to random orientations. (JEF)

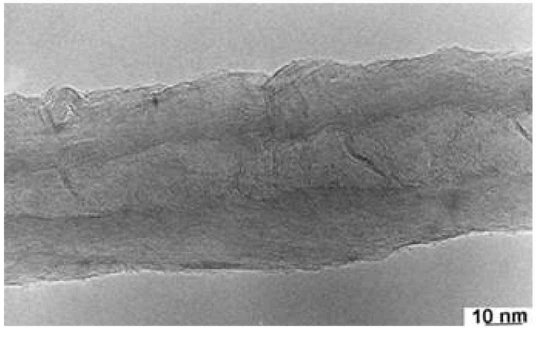
E040: Injection molding CNT composites – addition of up to 10% chevron CVD tubes to the resin requires no major changes in molding paramters.

E041: VGCF addition to shape-memory polymers; 1% leads to a doubling of the recovery stress.

E042: three-phase composites consisting of TiNi shape memory alloy, polymer, and VGCF for conductivity. Low percolation threshold.

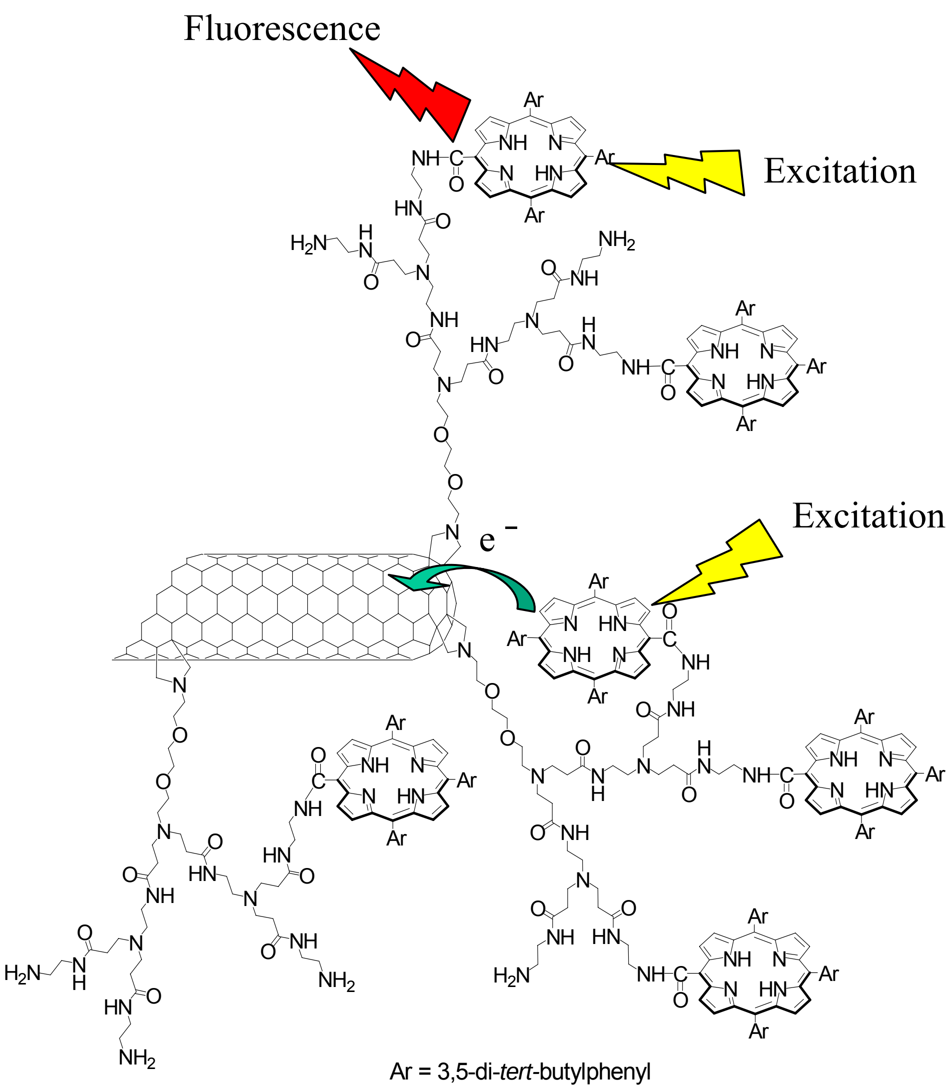
E047: carbon-carbon composite of carbonized Japanese cedar and CVD nanotubes – green materials and resource recovery:





By catalytic decomposition of C_2H_4, the growth of MWNTs was performed on arbonized samples at 1300°C after impregnation with [Fe (III)]

E063: SWNT functionalized with dendrimer + porphorins – claimed advantage is high graft density without destroying electronic properties, e.g fluorescence.



TGA:
- 1 functional group for 200 carbon atoms.
- In average only 2 porphyrins on a dendrimer.

Raman spectroscopy:
- No addition of ethylene diamine on the nanotube sidewall.
-Construction of the dendrimer on the functional groups.

Photophysical measurements:
- 2 different processes for the de-excitation of the porphyrins.
- Fluorescence and electron transfers.

Dr. Stéphane Campidelli, poster E063

THERMAL AND MECHANICAL PROPERTIES

E050: Bending WS_2 MWNT with AFM involves shear of adjacent shells. Expt gives C_{44} = 3 GPa, similar to 4 GPa for bulk MoS_2.

E052: Diameter-dependent radiation damage of SWNT with 20 -20KeV electrons and photons.

E053/062: Finite element analysis with C atoms as the "elements" and C-C bonds as the space frame. Youngs' modulus in agreement
with expt and "real theory".

E055: MD simulation of the length dependent thermal conductivity. The mode of thermal transport (ballistic vs. diffusive) and the relevant phonons depend on tube length w.r.t. mean free paths.

E059: AFM study of CNT combustion- surprisingly, mostly at sidewalls, not tube ends. Also very slow……… (see also Kashiwagi, Winey *et al* – fire retardation of polymers used in synthetic fabrics is improved by adding SWNT bundles)

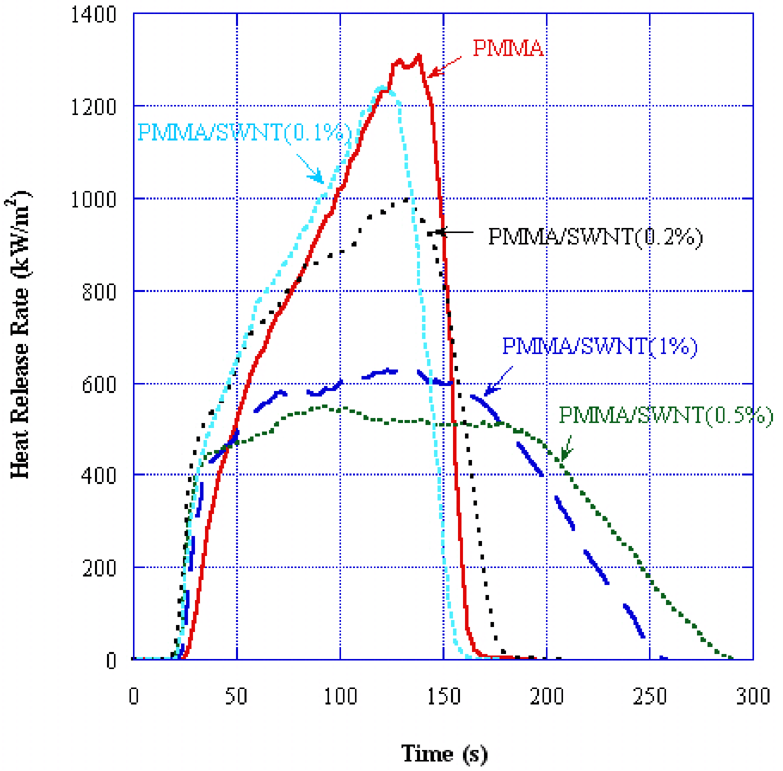


Figure 8. Effects of SWNT concentration on heat release rate curve of PMMW/SWNT at 50 kW/m^2.

E060: Butt-welding MWNT-DWNT junctions in the TEM – current pulse > a threshold value "joins" the two tubes, **one C-C bond at a time.** Force to pull them apart proportional to the # of current pulses, i.e. # of C-C bonds.