3.22 Mechanical Properties of Materials
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Carbon Nanotube Mechanics

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http://en.wikipedia.org/wiki/Image:Kohlenstoffnanoroehre_Animation.gif

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Big Picture

- Macroscopic description of the phenomenon
  - Very high tensile strength, but buckles easily in compression (11-63 GPA, 100-1000x better than ASTM 1040 steel) [1]
  - Very high Young's Modulus (~1 TPa)
  - Buckling behavior very similar to deformation of cylindrical shells [2]

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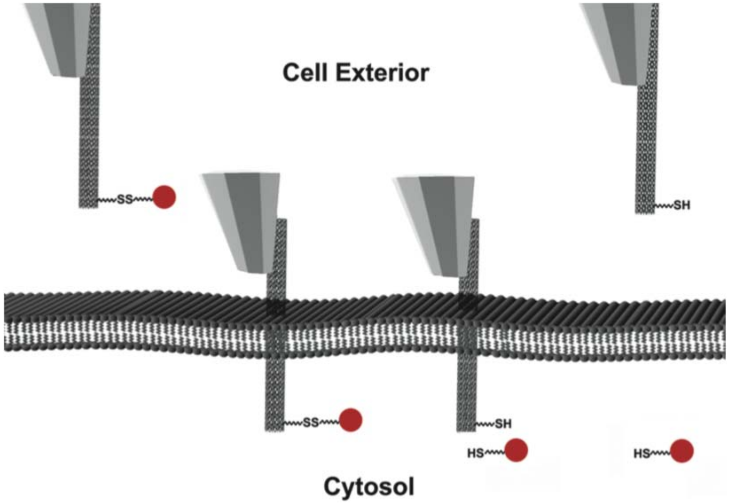
Please see Fig. 3b,c,d in [2].

Source: Chen, Xing, et al. "A cell nanoinjector based on carbon nanotubes." *PNAS* 104 (20 May 2007): 8218-8222.



- Engineering applications of Carbon Nanotubes
  - Composite materials to take advantage of high tensile strength
  - Cell nano-injection - Delivery of chemical load into cells without solvents and without damage of the cell membrane [3]

[1] Pantano, A., et al. "Mechanics of deformation of single- and multi-wall carbon nanotubes." *Journal of the Mechanics and Physics of Solids* 52 (2004): 789-821

[2] Poncharal P., et al. "Electrostatic Deflections and Electromechanical Resonances of Carbon Nanotubes." *Science* 283 (1999): 1513-1516

[3] Chen, X., et al. "A cell nanoinjector based on carbon nanotubes." *PNAS* 104 (20 May 2007): 8218-8222

Microscopic mechanism

- Microscopic behavior of Carbon Nanotube Failure
  - Failure proceeds via breaking of C-C bonds
  - Fracture propagation direction is a function of chirality [4]
  - Sword-in-Sheath Failure predominant in MWCNT structures [5]

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Please see Fig. 6 in [4] and Fig. 1 in [5]

[4] Belytschko, T., et al. "Atomistic Simulations of Nanotube Fracture." *Physical Review B* 65 (2002): 235430.

[5] Yu, M. F., et al. "Controlled sliding and pullout of nested shells in individual multiwalled carbon nanotubes." *Journal of Physical Chemistry B* 104 (2000): 8764-8767

Prediction & Optimization

- Prediction
  - Resonance can be modeled as a thin-walled cylindrical cantilever beam [2]

$$\nu_j = \frac{\beta_j^2}{8\pi}\frac{1}{L^2}\sqrt{(D^2 + D_i^2)}\sqrt{\frac{E_b}{\rho}}$$

- Optimization of CNT Mechanical Properties
  - Minimization of crystalline defects is critical
  - Chirality has a lesser influence on strength [4]

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Please see Fig. 2 in [2] and Fig. 8 and 9 in [5].

Case:	Failure Strain:
Pristine Armchair	18.7%
Pristine Zig-Zag	15.5%
5/7/7/5 Armchair	14.3%
One Atom Removed	***10%***