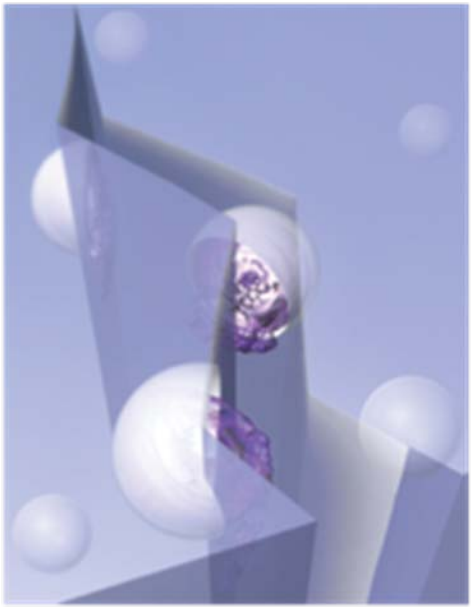
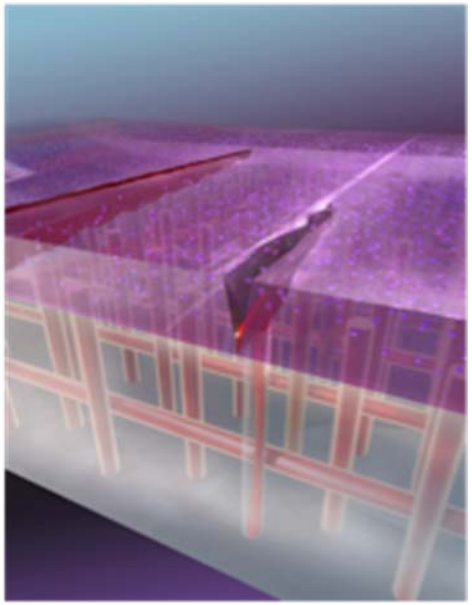
Self-Healing Materials for Recovery of Structural Resilience





Nancy R. Sottos

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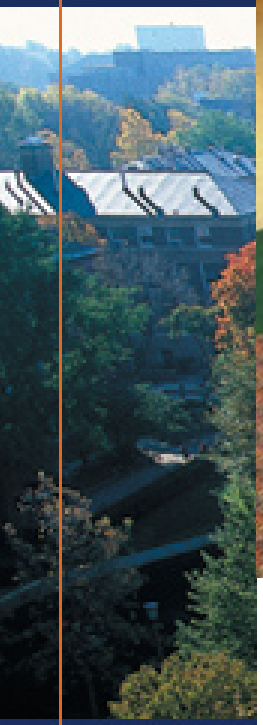
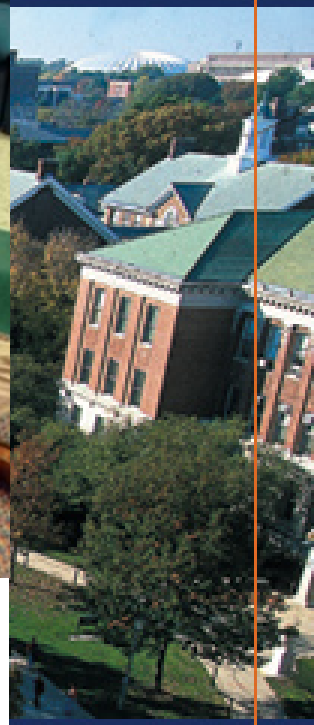
University of Illinois at Urbana Champaign

Autonomic Materials Systems Group





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AT URBANA-CHAMPAIGN

Autonomous Healing

Autonomic or Self-healing Functionality:

The ability to repair damage in an automatic and site specific fashion <u>without</u> manual intervention.

Damage Length Scales

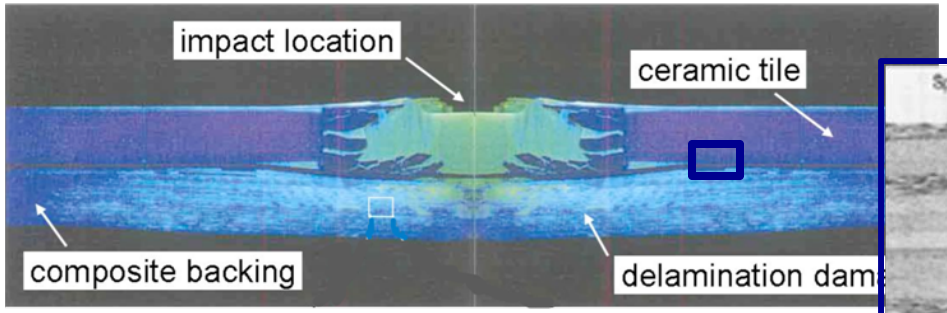
100 mm

1 mm

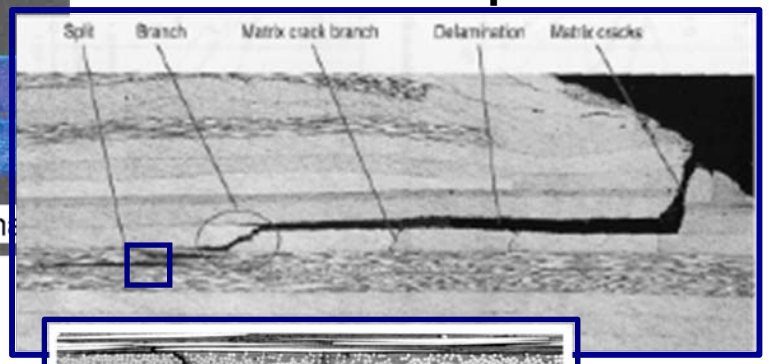
100 um

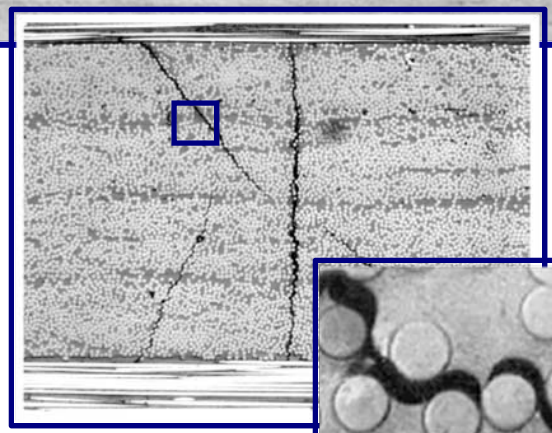
10 um

Blast Damage

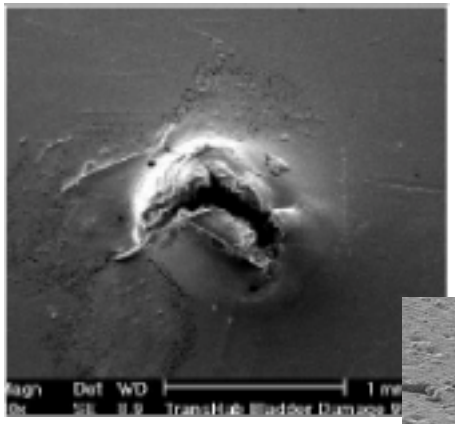


Laminated Composite

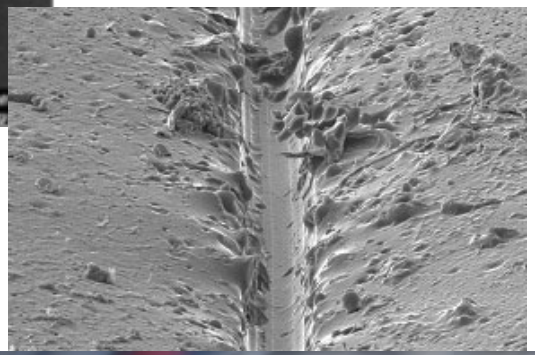


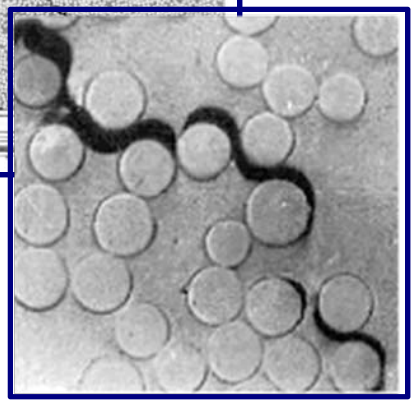


Puncture Damage



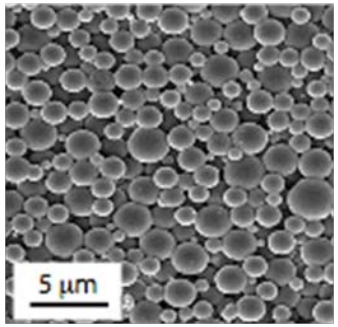
Coating Damage





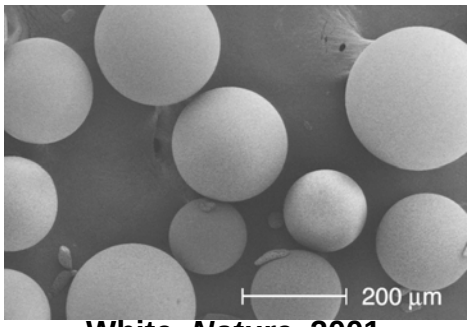
Storage of Liquid Healing Agents

Microcapsules ~1 um



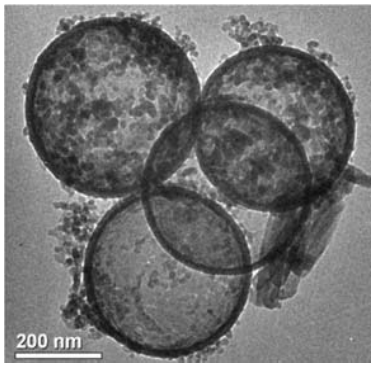
Blaiszik, *Comp. Sci. Tech, 2008*

Microcapsules ~200 um



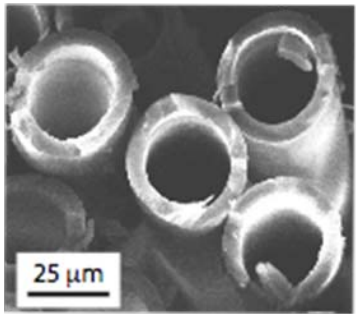
White, *Nature*, 2001

Nanocapsules



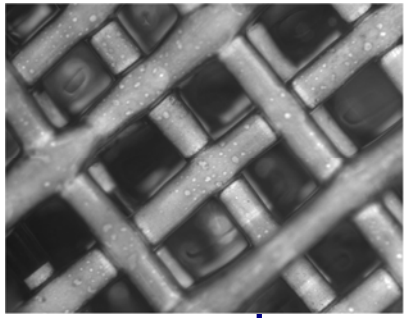
Blaiszik, *Comp. Sci. Tech, 2008*

Hollow glass fibers



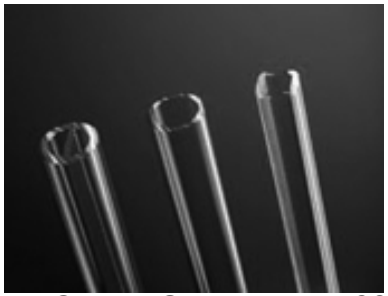
Pang, *Comp. A*, (2005)

Microvascular networks



Therriault, *Nat. Mat.*, (2003)

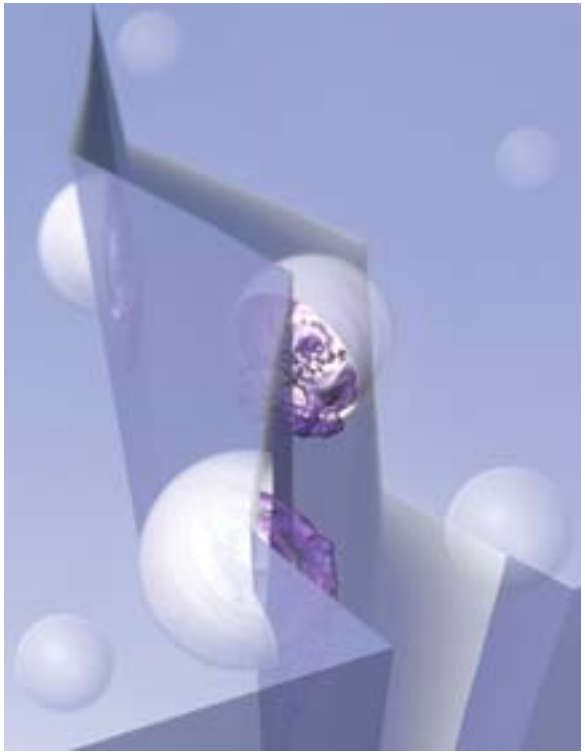
Glass capillary tubes

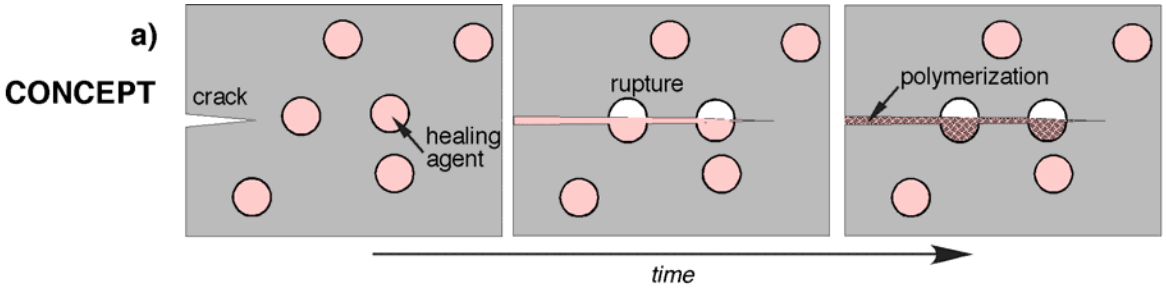


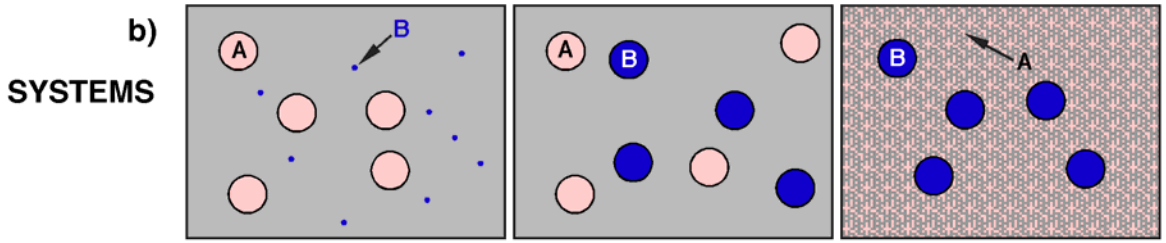
Dry, *Comp. Structures*, 1995

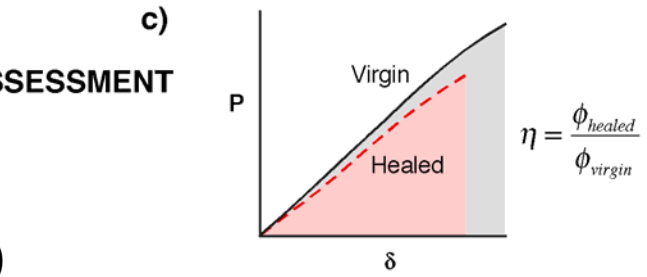
100 nm — **10um** — **100 um** — **1 mm**

Microencapsulated Systems







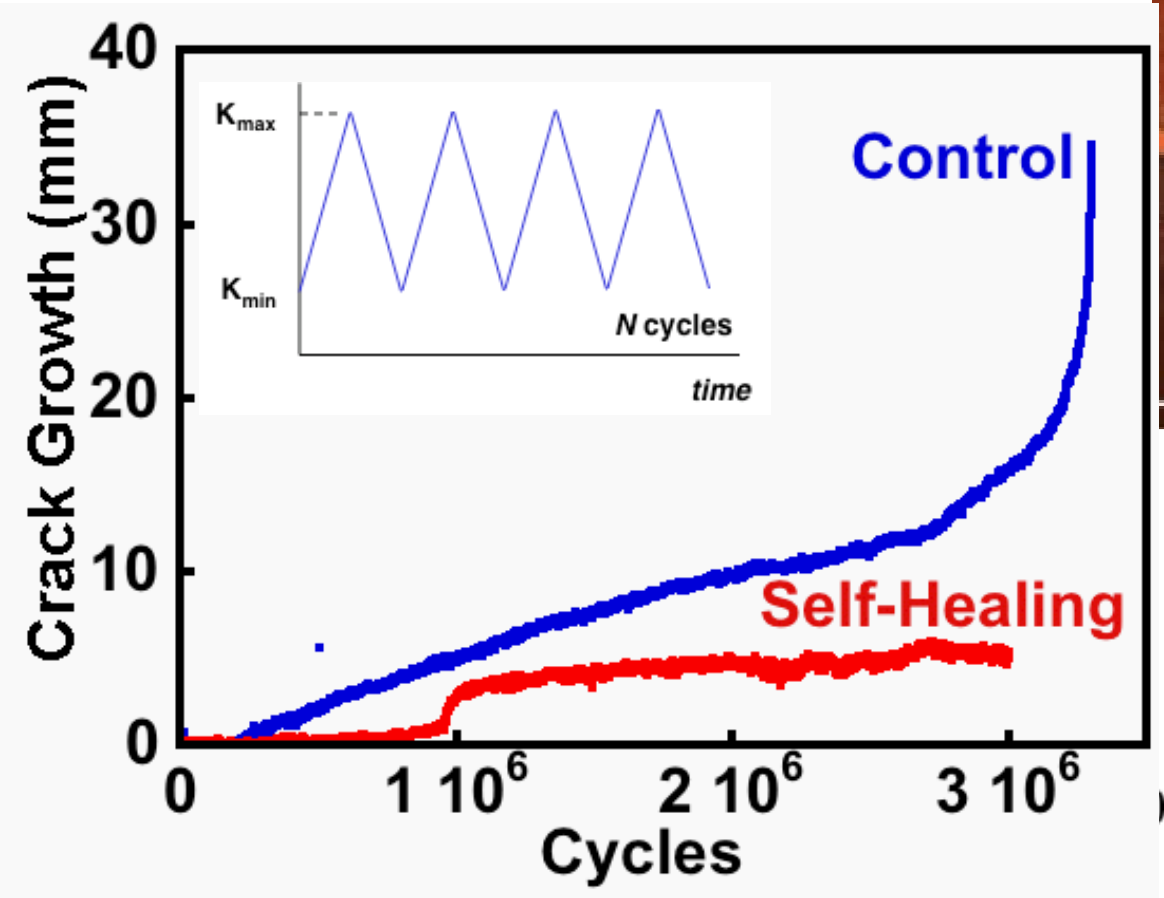


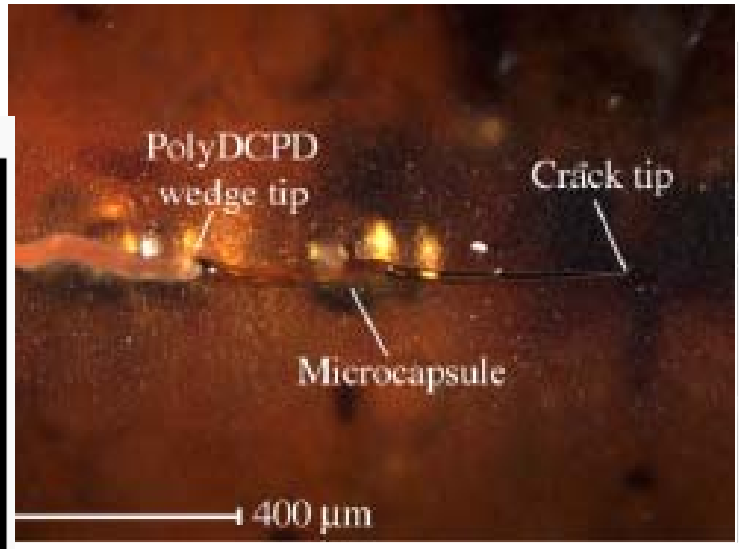
Symbol	ϕ	Metric
η	K_{IC}	fracture toughness
η'	U	fracture energy
η_E	E	stiffness
η_σ	σ_{ult}	ultimate strength
η_T	T	tear strength

White et al., *MRS Bulletin* (2008)

Healing of Mode I Crack Damage in Polymers

Healing “on the fly” during fatigue





2.5 wt% Grubbs catalyst
5 wt% microcapsules

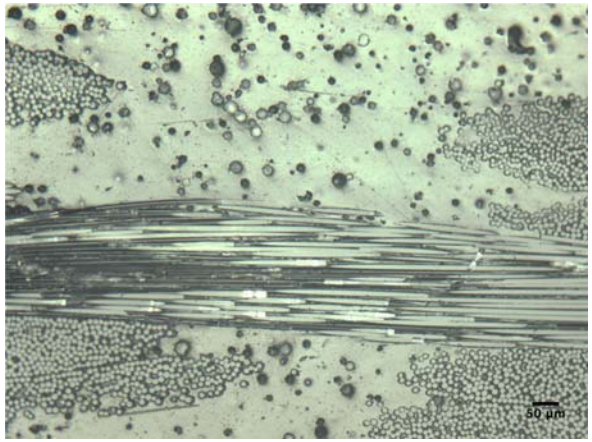
Healing conditions:
room temperature, 48 h

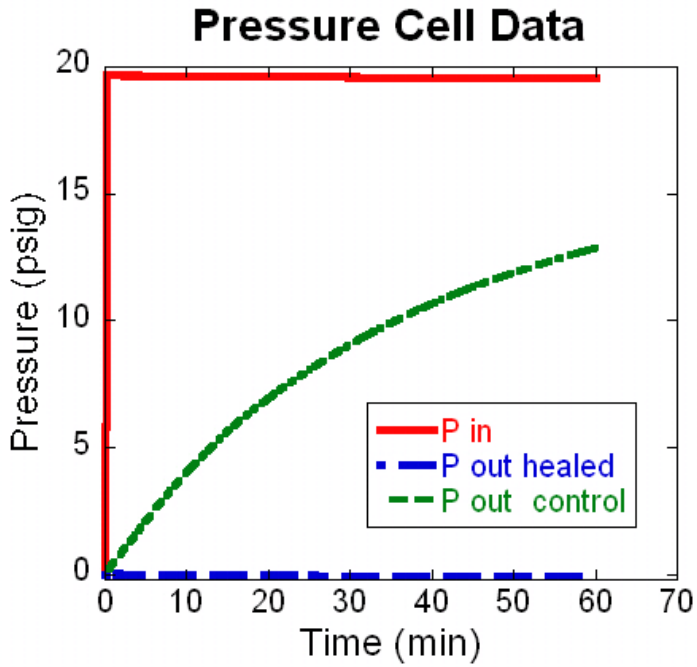
Brown et al., *Experimental Mechanics* (2002)

Self-Sealing of Puncture Damage

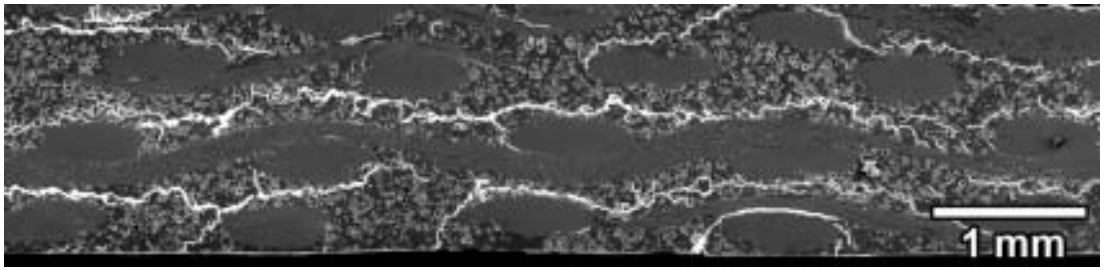
Application: Cryotanks

20 um capsules mixed in epoxy resin with woven glass

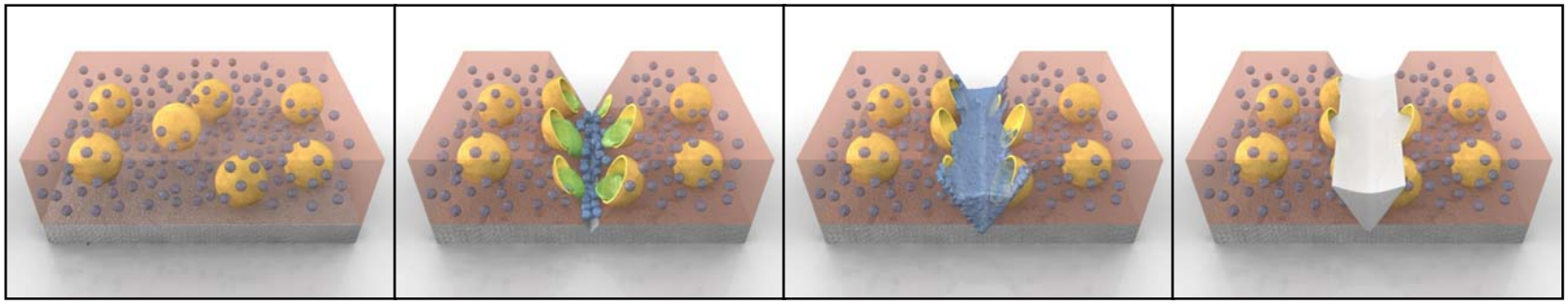




Successful self-sealing of microcrack damage in a woven glass composite with 20-50 um capsules

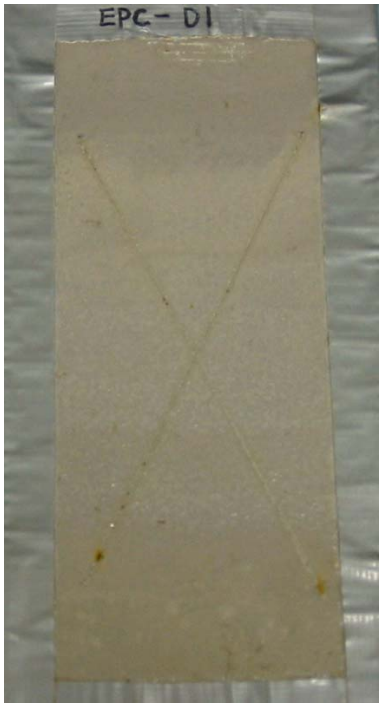


Self-Healing Coatings



Control **Self-healing**

Cho et al. *Advanced Materials* (2009)



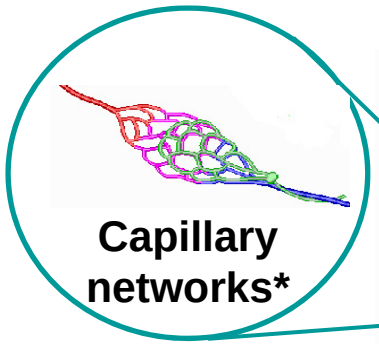
20 hr. exposure to salt water

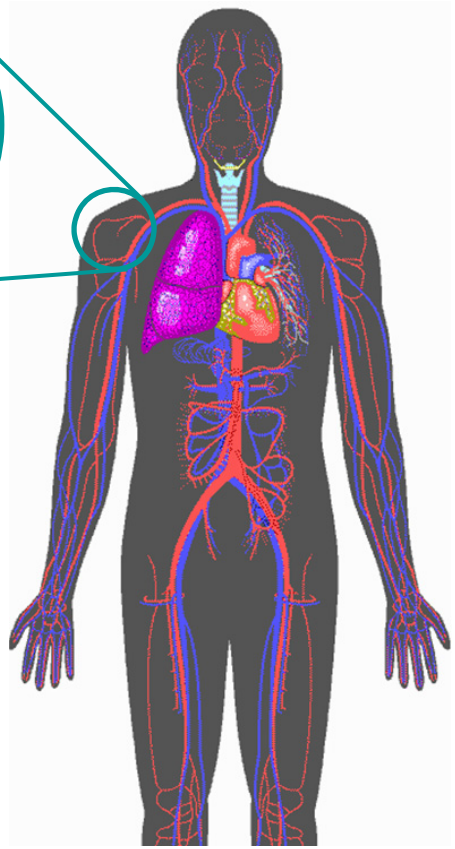
Remaining Challenges

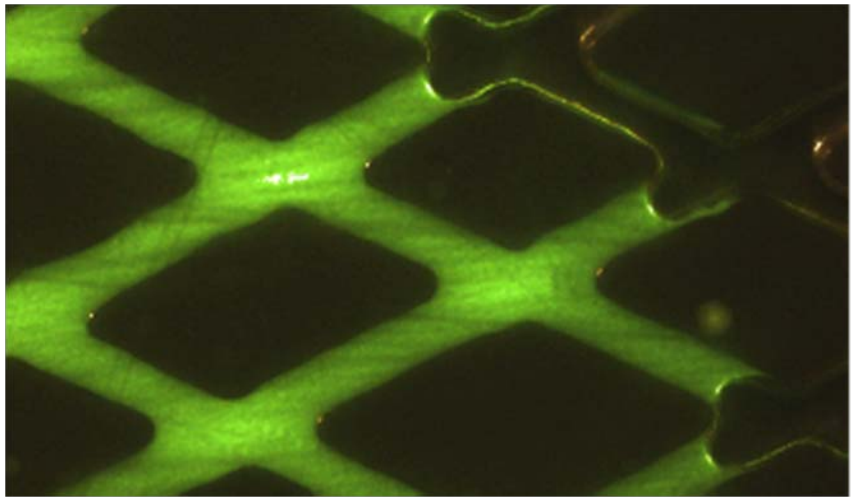
- Smaller length scales.... is nano feasible?
- Healing agent stability (high temps, humidity,...)
- Capsule stability
- Repeated healing
- Larger damage volumes

Microvascular Based Systems

Continuous delivery of healing agent for repeated healing cycles



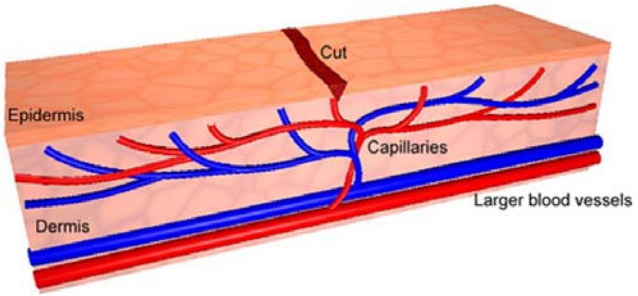


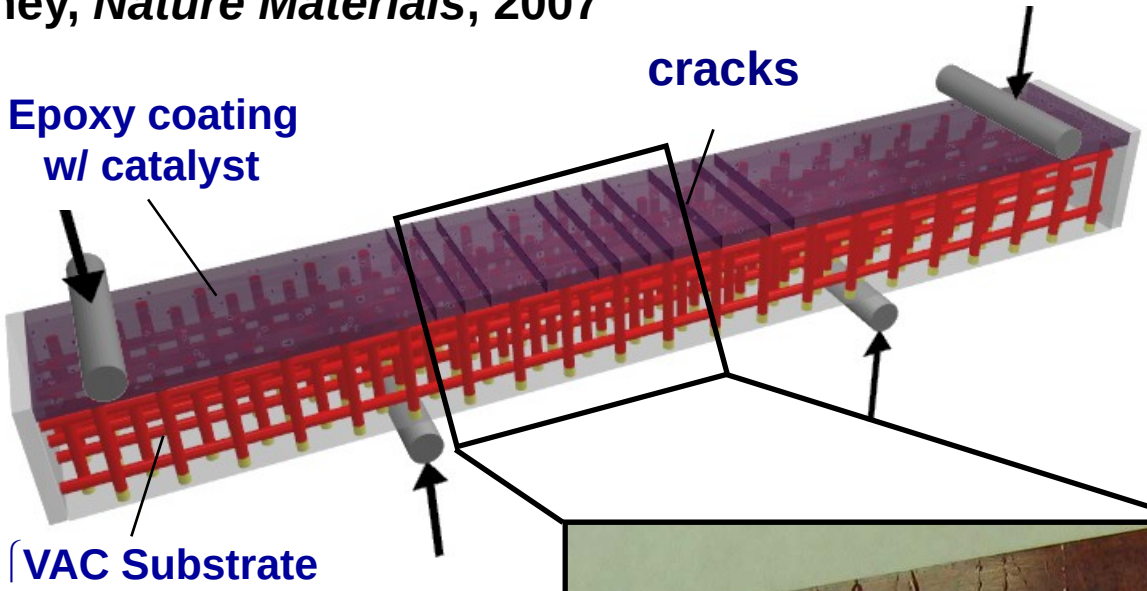


Continuous Self-Healing Coatings

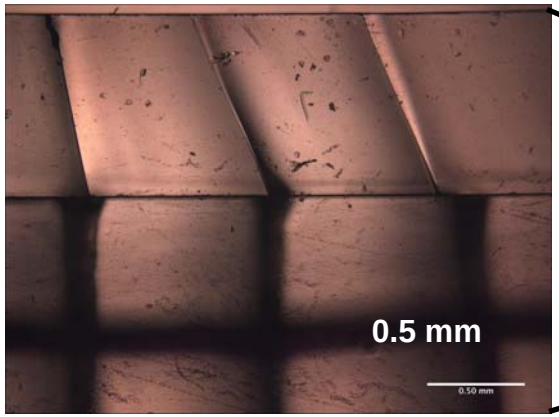
Bioinspiration

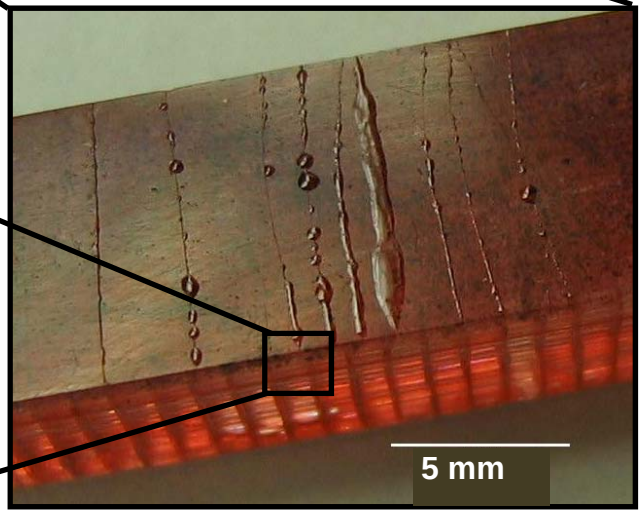
Toohey, *Nature Materials*, 2007





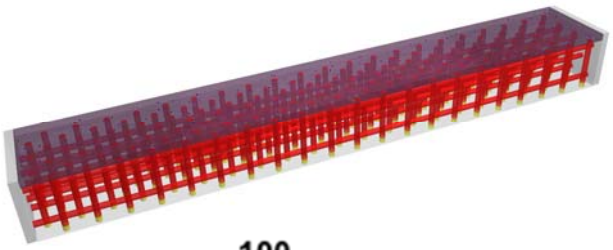
coating



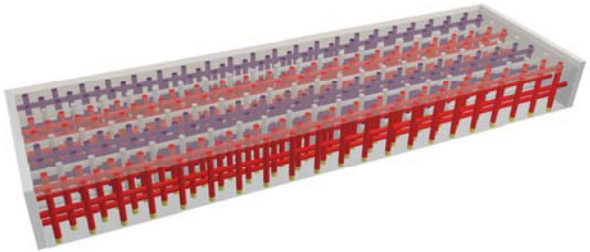


Continuous Self-Healing Coatings

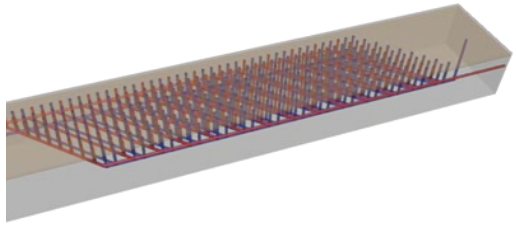
Single network: DCPD/Grubbs

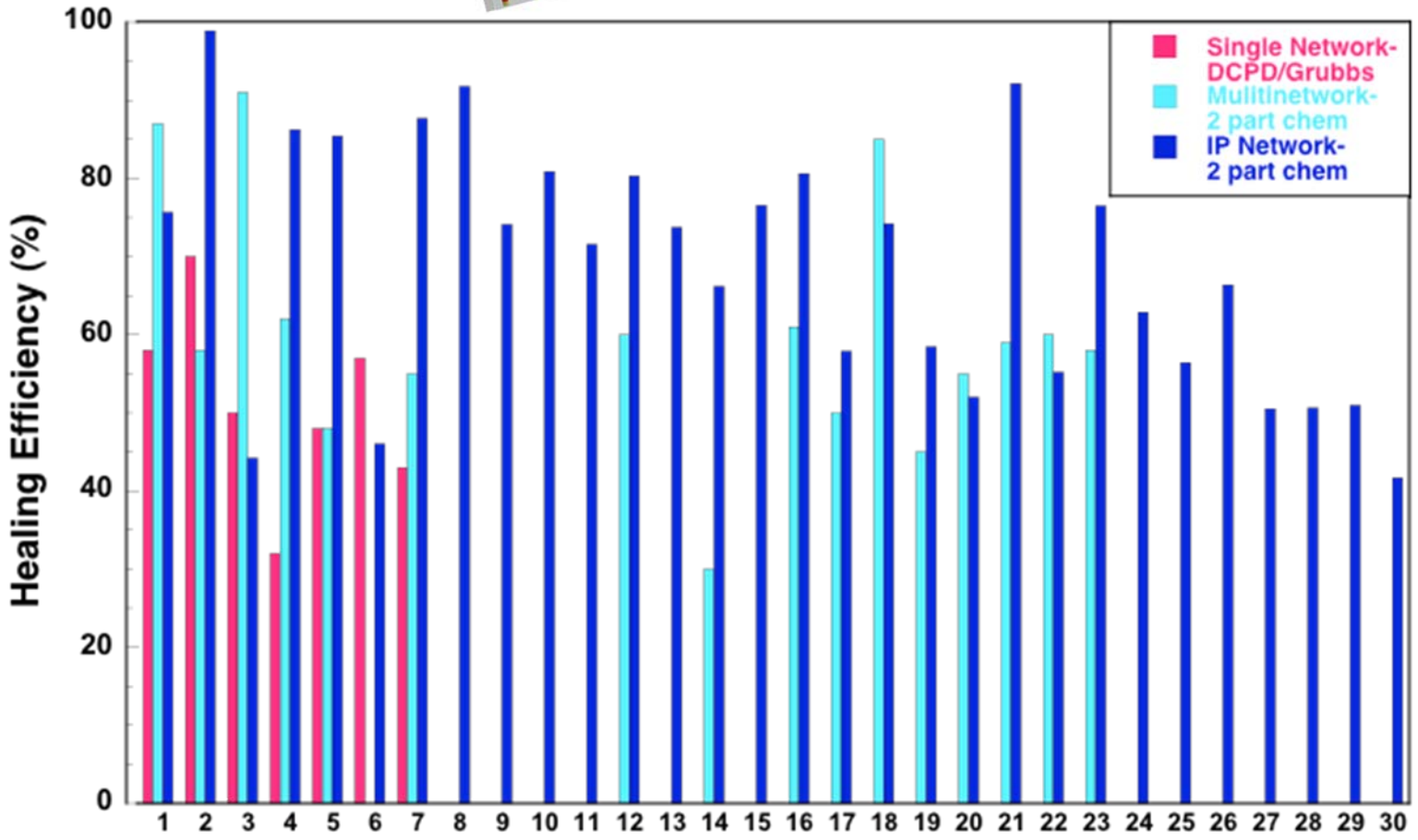


Multi-network: 2 part epoxy



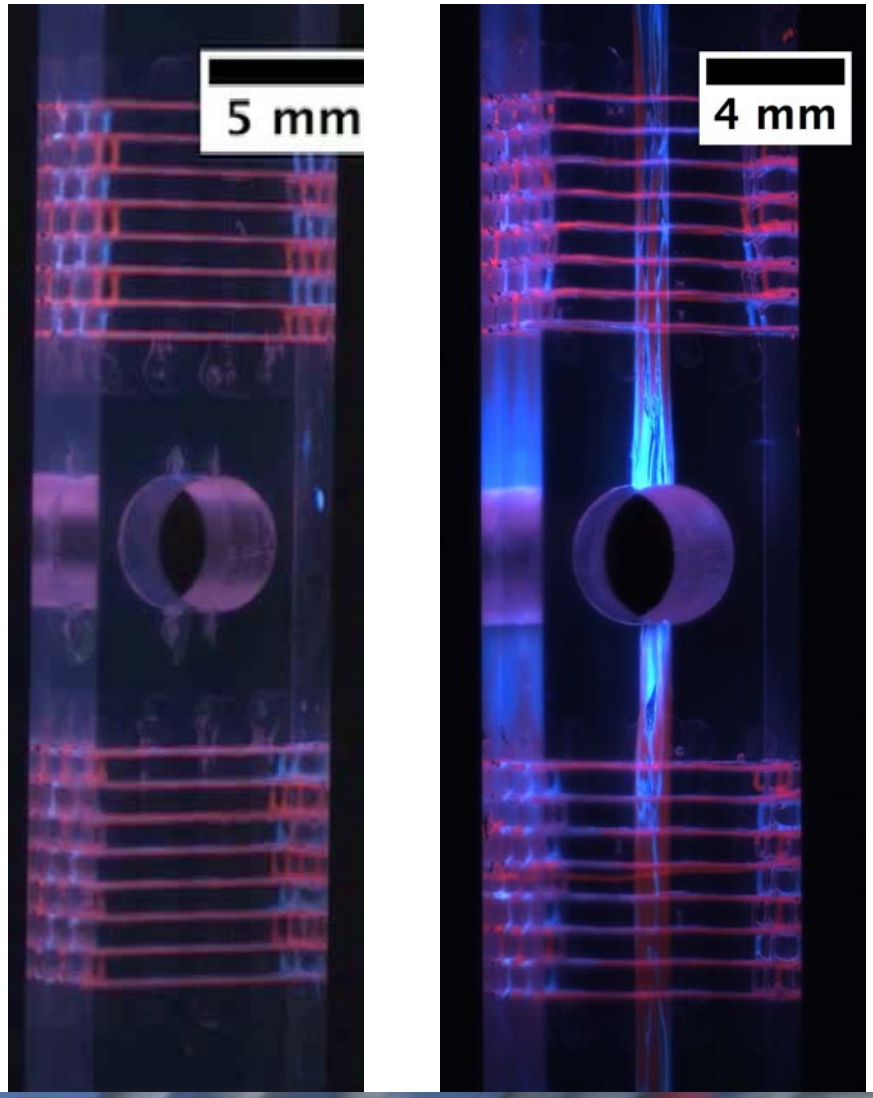
IP-network: 2 part epoxy

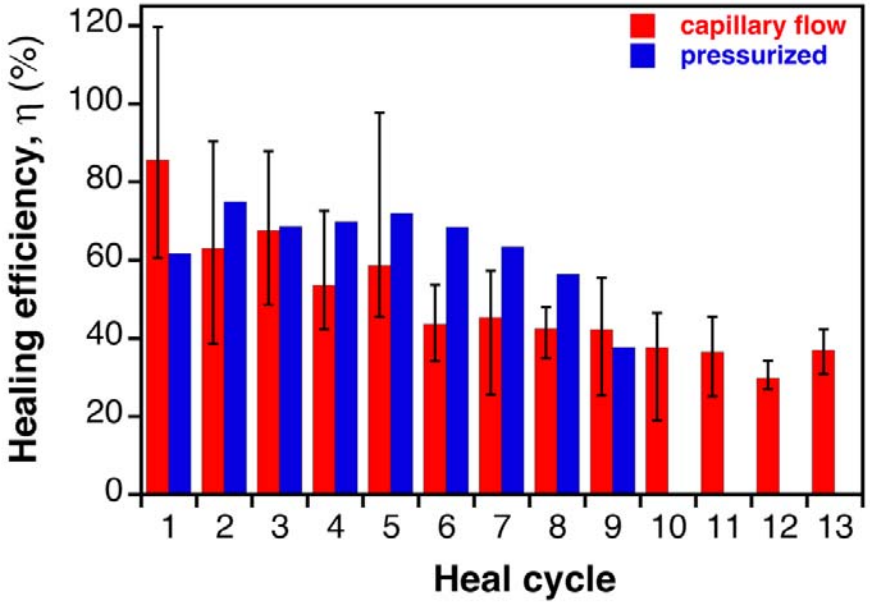




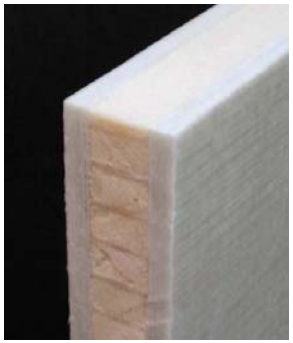
Hansen et al., *Adv. Mat.* 2009

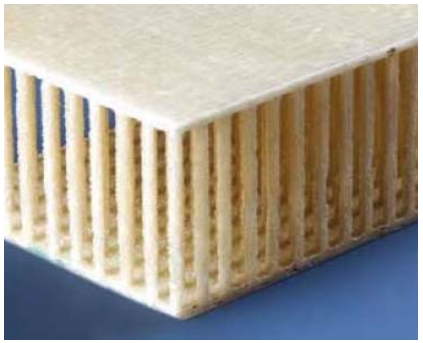
In situ Microvascular Healing

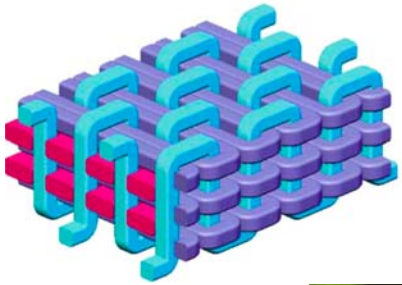




Strategy for Blast Resistant Sandwich Structures

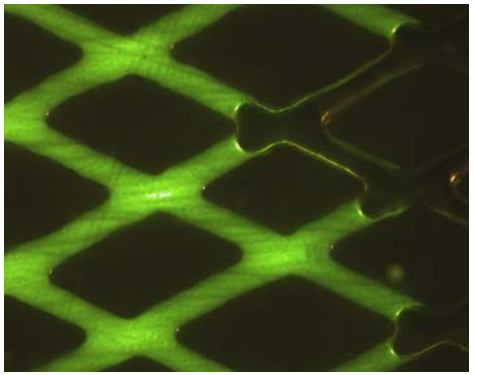






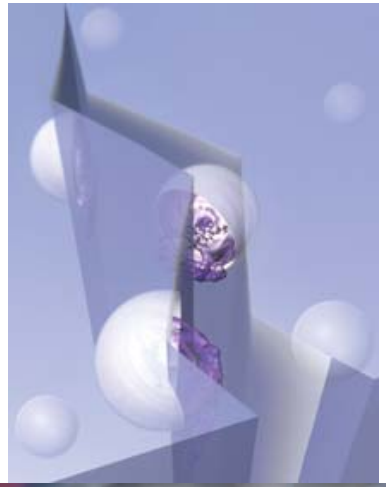
3D woven composite
face sheet delamination

3TEX



Microvascular Healing

Polyurethane (PU)
foam core shear failure



Microcapsule Healing

Remaining Challenges

- Circulation – mixing and pumping
- Channel blockage
- Incorporation with structural reinforcement
- Addition of other functionalities – e.g. cooling
- Is regeneration and remodeling possible?