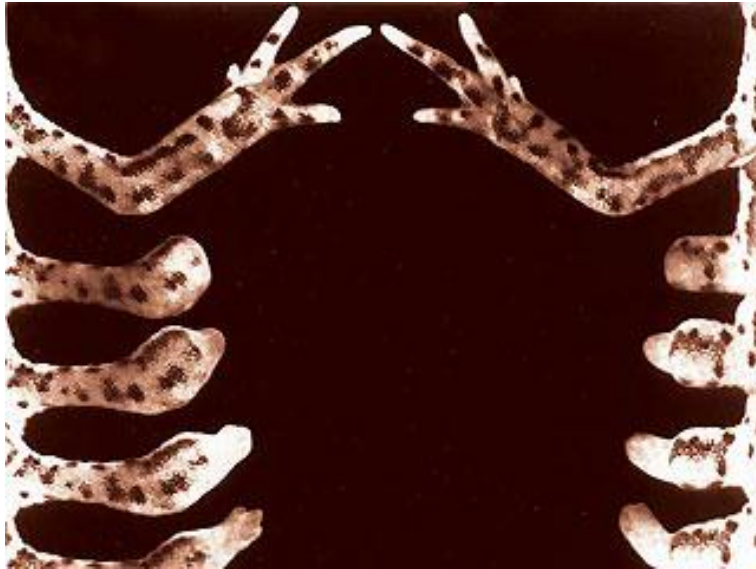


Regeneration and Remodeling of Materials



<http://www.foxnews.com/story/0,2933,307739,00.html>



<http://cache.eb.com/eb/image?id=98328&rendTypeId=4>

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& Beckman Institute for Advanced Science and Technology**

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Outline

- Program overview
- Regenerative coatings
 - acrylic system
 - surface microvalves
- Dynamic polymer
 - bi-phase system
 - regeneration experiments
- Multiscale scaffolds
- Summary

Autonomous Materials Systems Group

Regeneration & Remodeling Team



Ryan Gergely (AE)



Windy Turchyn (Chem)



Brett Krull (MatSE)

Concepts and Motivation

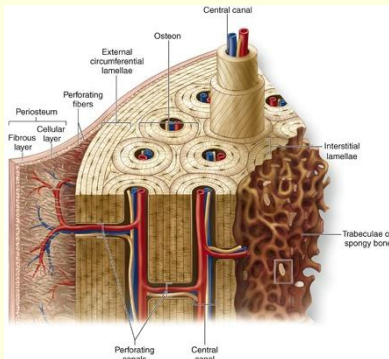
Regeneration and Remodeling in biology:

Tree skink lizard



Linckia starfish

Human Bone



Key Features:

- Large scale damage volume
- Repeatability and Reversibility
- Orders of magnitude change in properties
- Autonomy
- Stress activation

Benefits:

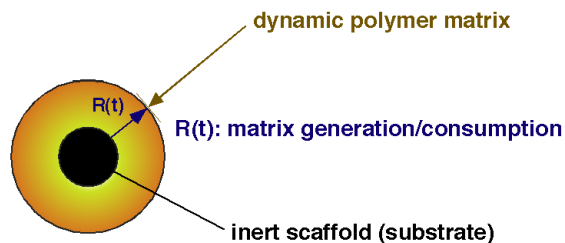
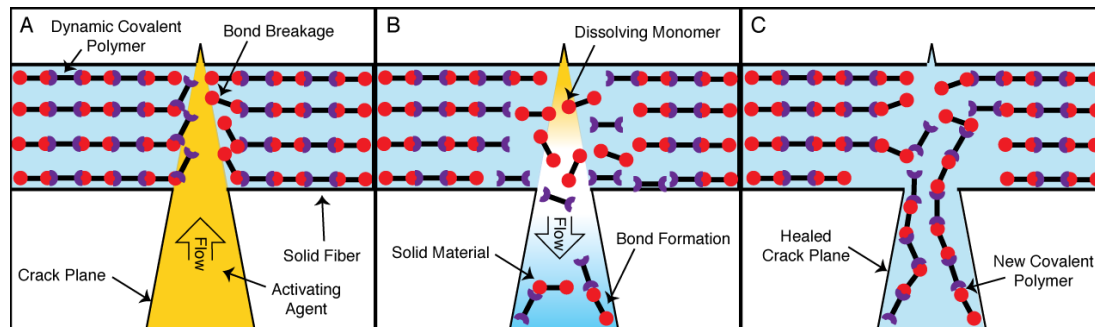
- Selective restructuring
- Response to environmental stimuli
- Reduction in parasitic weight
- Anti-aging
- Self-repair

Overview

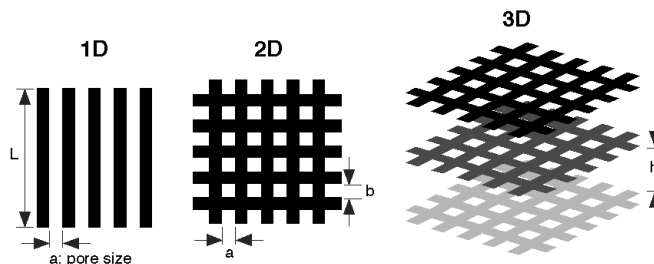
Regeneration in biology:



Our approach: *Dynamic polymers*



+ *inert scaffolds*



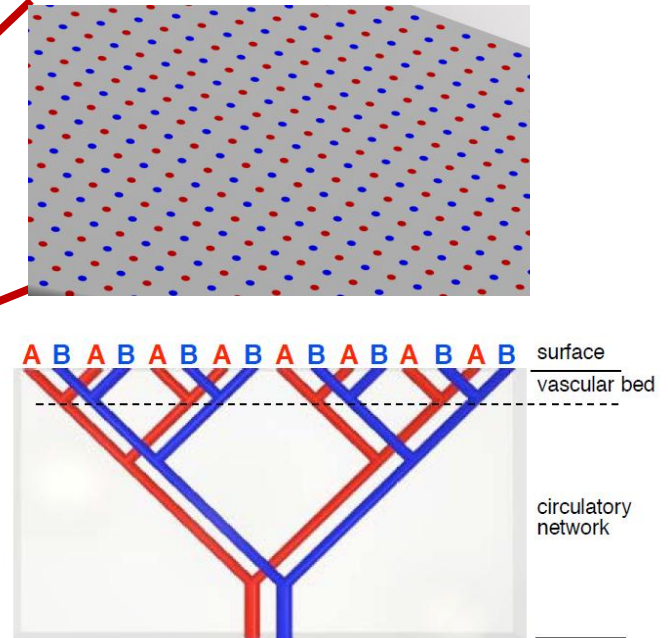
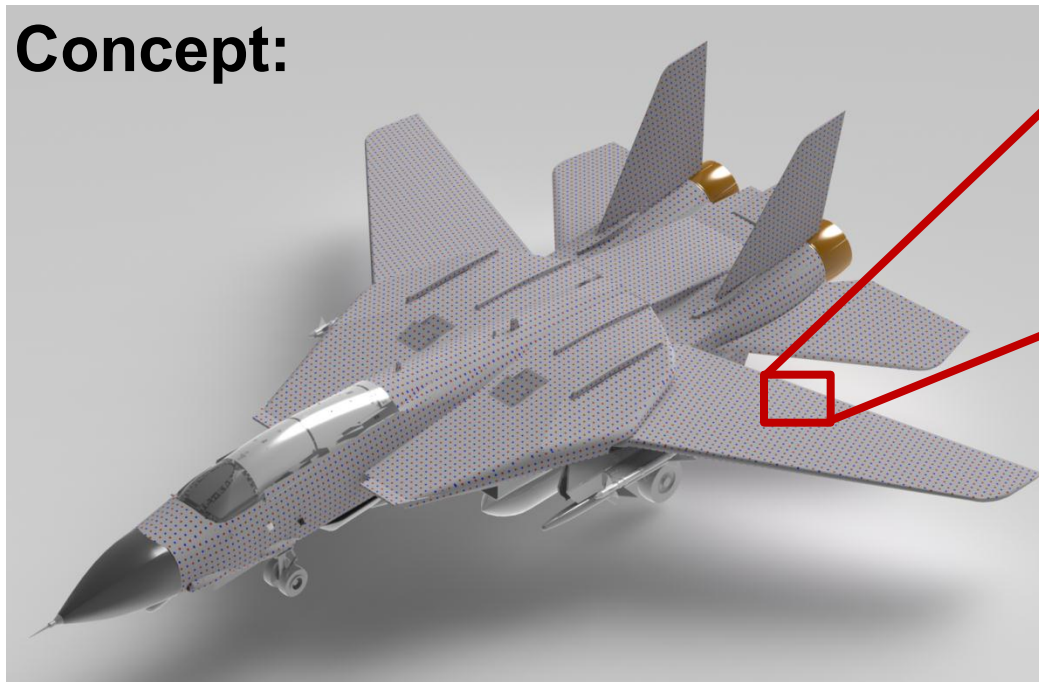
GOAL: To develop bio-inspired composite material systems that regenerate and remodel in response to environmental stimuli.

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Coating Regeneration

Concept:



Coating Damage
Triggers Release

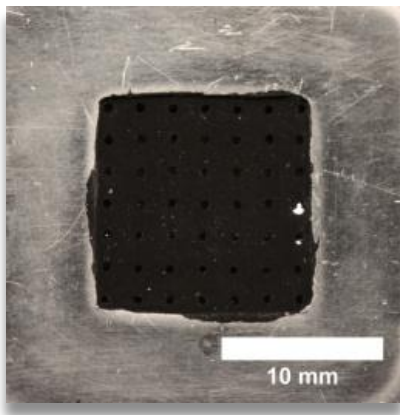
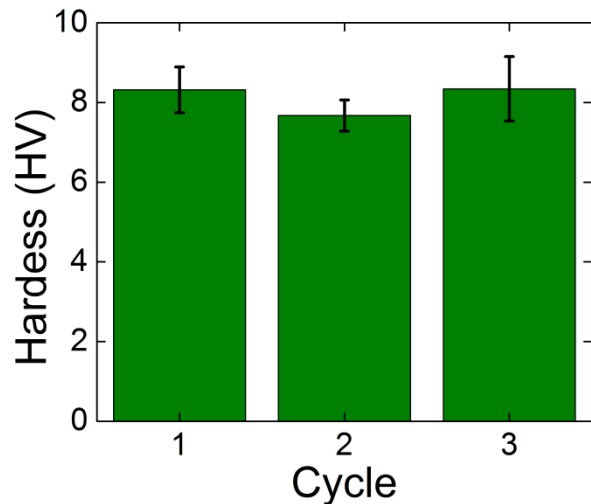
Delivery of
Uncured Coating

Vasculature
Substrate

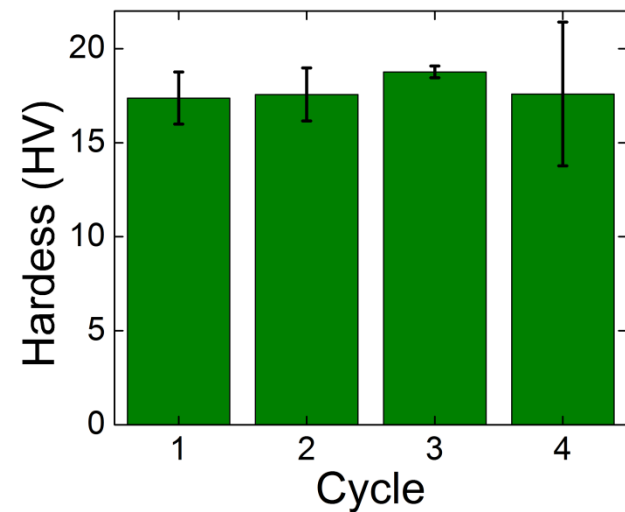
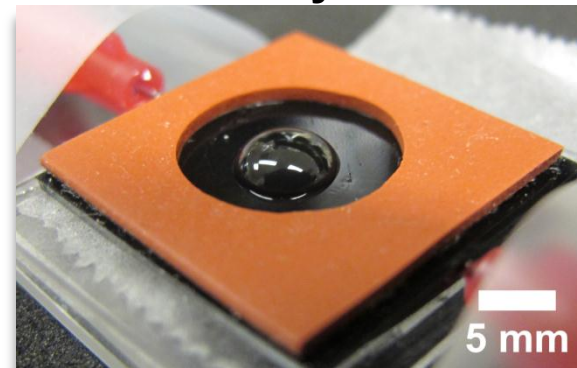
- Current healing technology targets small scale damage (cracks)
- Extensive damage is difficult to heal
- Channel blockage is a challenge

Surface Microvalves

Prior Results

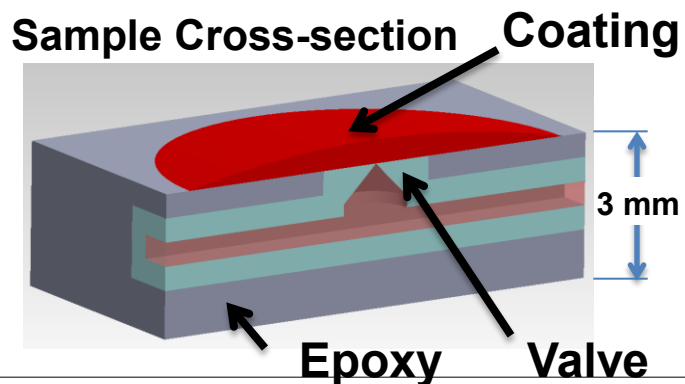
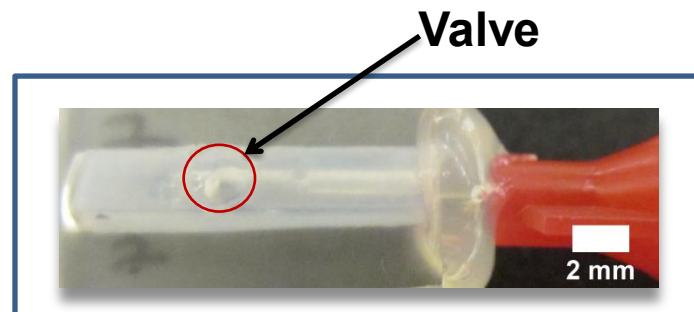
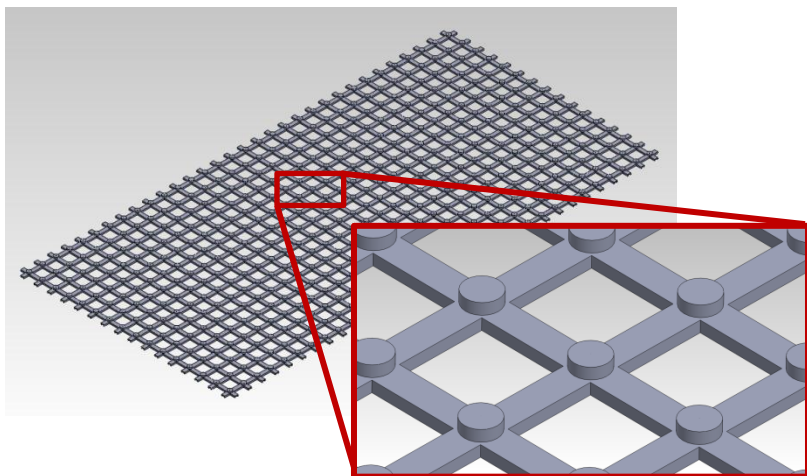


Valved Pores Prevent Curing into Delivery Network

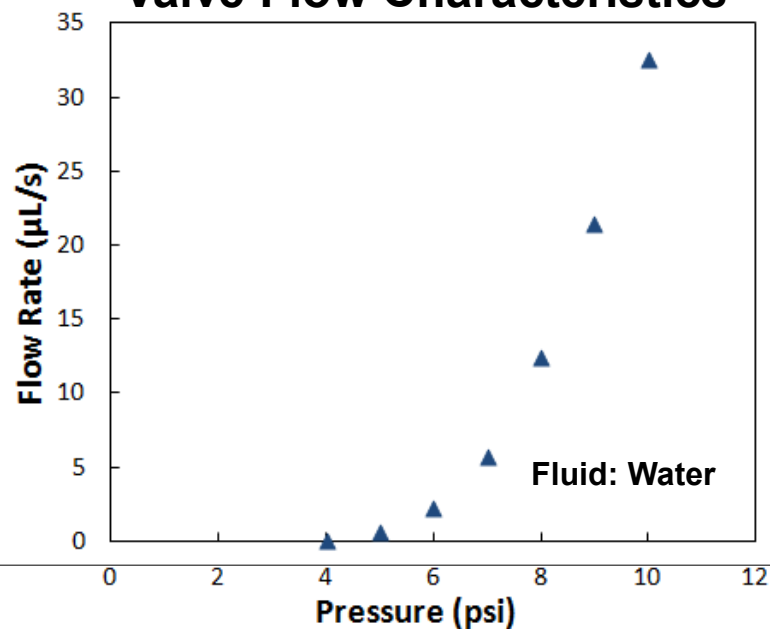


Valve Network Design

valve network



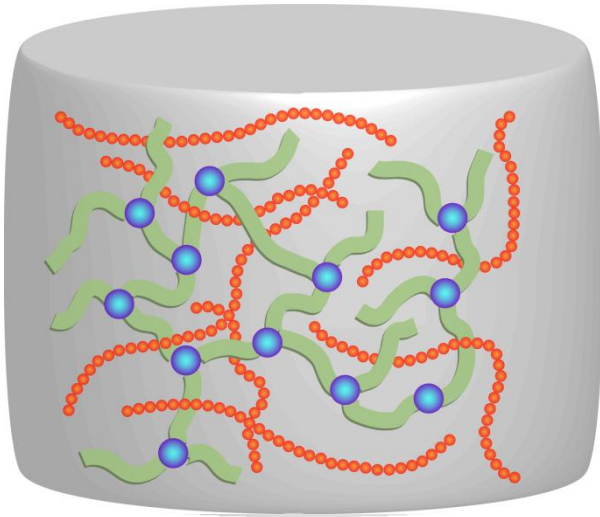
Valve Flow Characteristics



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Bi-Phase Chemical Resin



-  Acylhydrazone end-functionalized PEG oligomer
-  Tri-aldehyde crosslinker
-  Methacrylate liquid monomer (HEMA)

Deng et al. *Macromolecules*, 2010, 43, 1191-1194

Sol

- Concept:** Low viscosity solution for easy delivery via microvascular networks
- Design:** Consists of gelator components in liquid monomer “solvent”

Gel

- Concept:** Rapid viscosity increase to a semi-solid as first transition
- Design:** Acid catalyst initiates gel formation at time, t_1

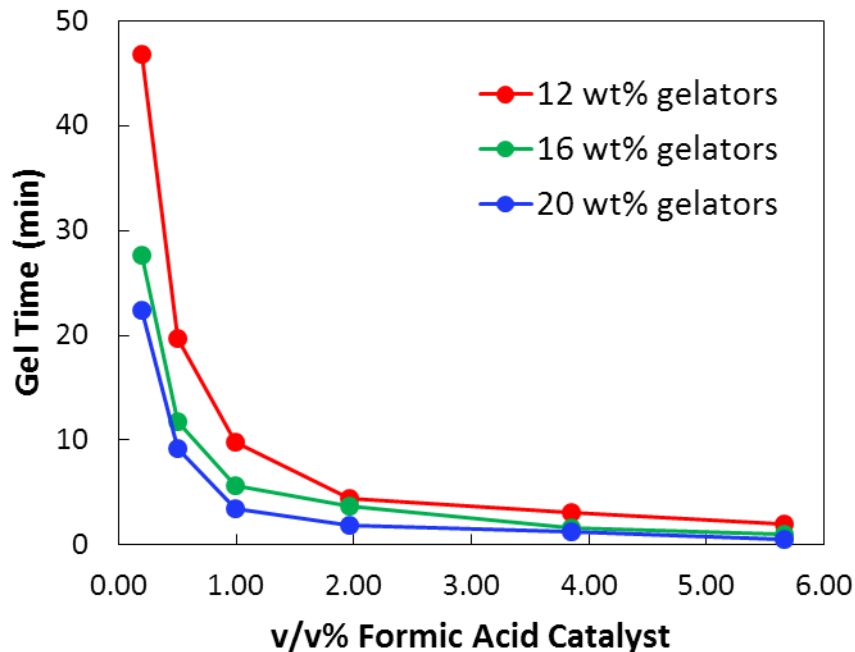
Polymer Solid

- Concept:** A second stage transition for recovery of mechanical strength of damaged region
- Design:** Monomer (HEMA) polymerizes at time, t_2 , by initiator/promoter

Individually Tunable Chemistries

t_1 Gel Time

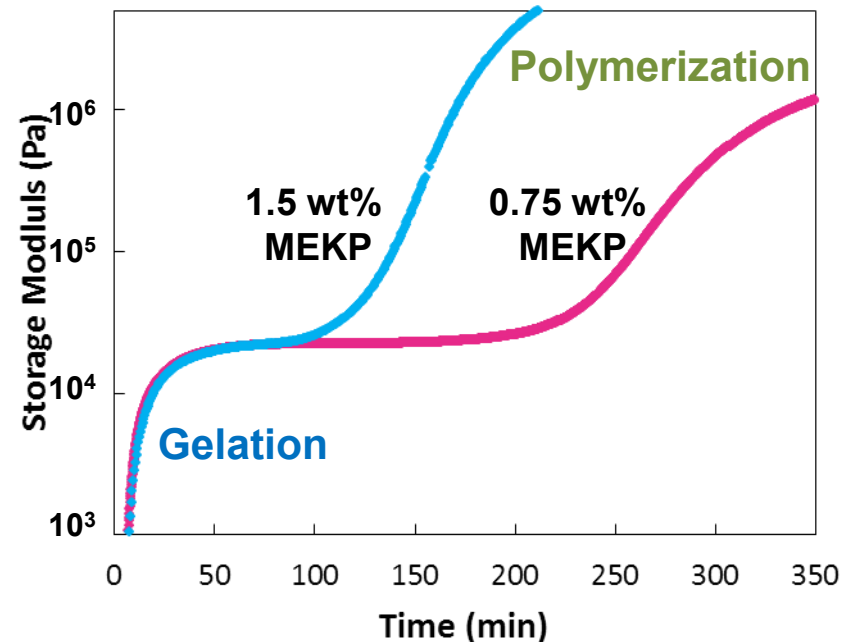
Controlled by acid catalyst & amount of gelators



t_2 Polymerization Time

Room Temp. Polymerization Components

- Initiator – MEKP
- Promoter – CoNp



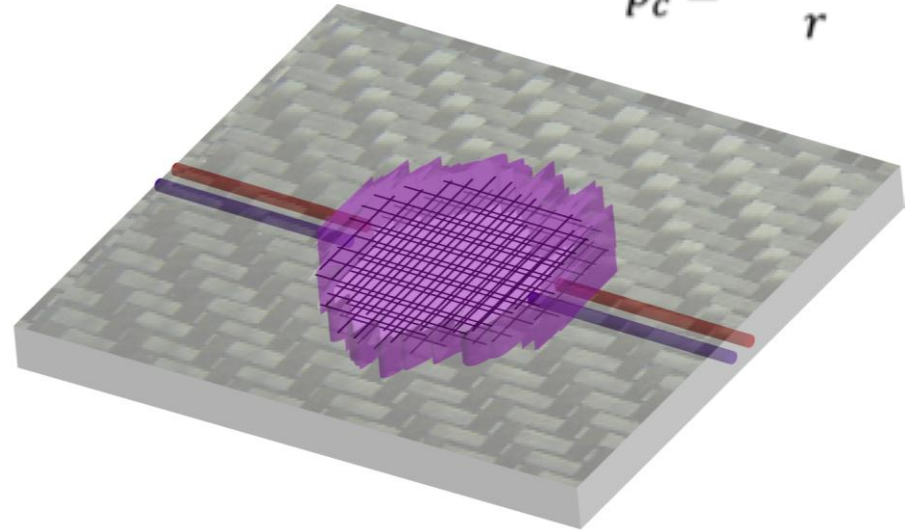
(Polymerization: 0.3 wt% CoNp, 15 v/v% acetic acid catalyst)

Scaffold for Large Damage Volume

$$p_c = \frac{2\gamma \cos \theta}{r}$$

Infiltrate Scaffold

- Small pores fill with resin due to surface tension
- Sufficient healing agent delivery possible smaller volumes



Gel Scaffold

- 2-component bi-phase gel/polymer system
- Gradual material deposition and solidification
- Gel network scaffold fills large volumes
- Subsequent polymerization and recovery of virgin properties

Part A

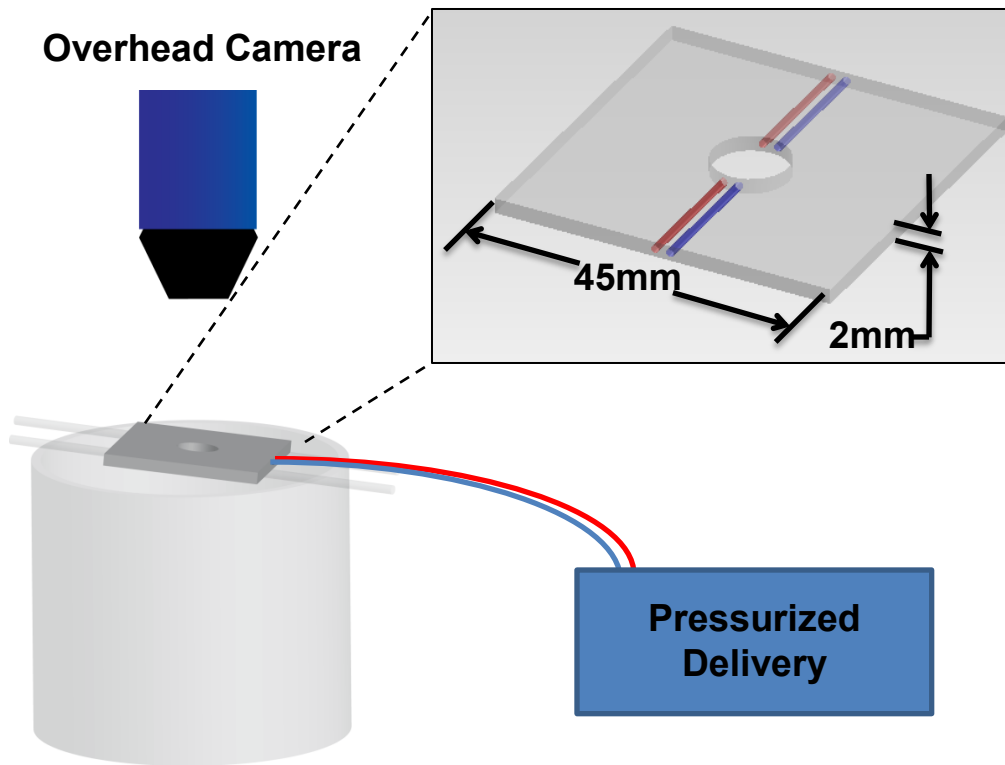
Monomer
Acid Catalyst
Gel Part 1

Part B

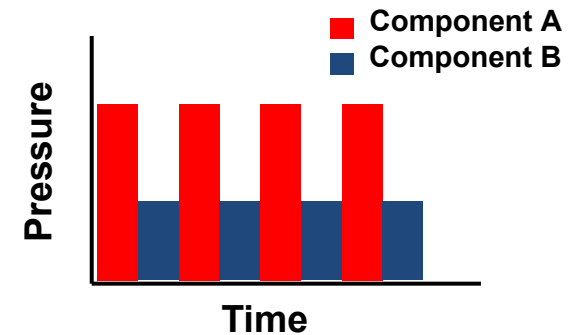
Monomer
Gel Part 1
Gel Part 2

Large Damage Volume Regeneration

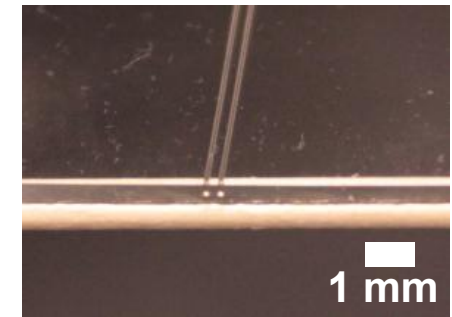
Damage Regeneration Setup



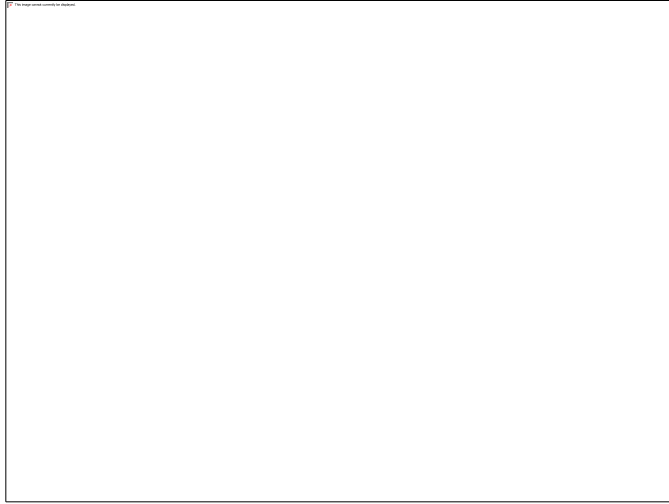
Damage Fill Pumping Regime



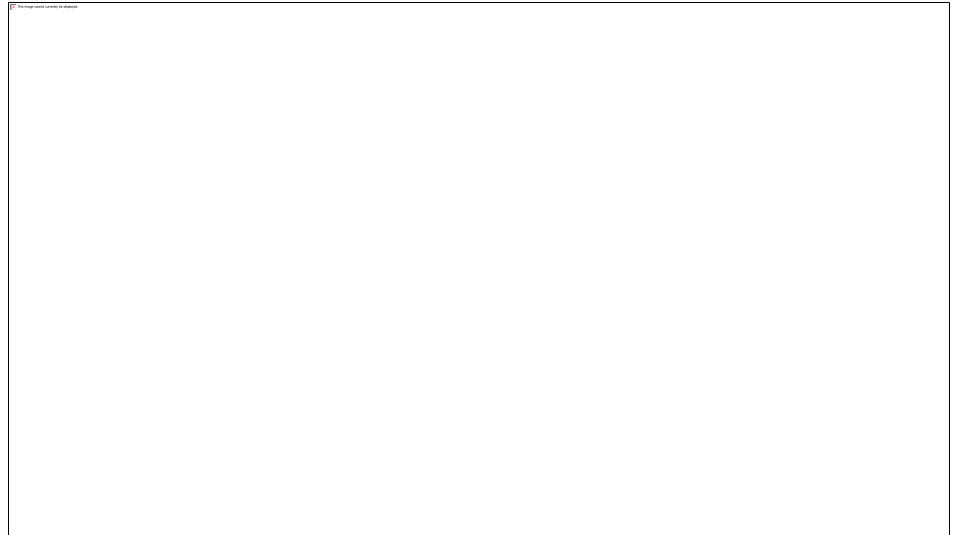
Microchannels in Specimen



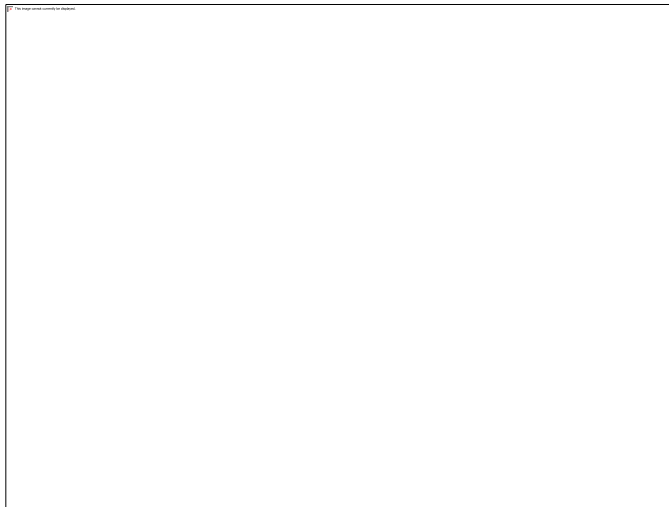
3.5 mm gap (PDMS healing system)



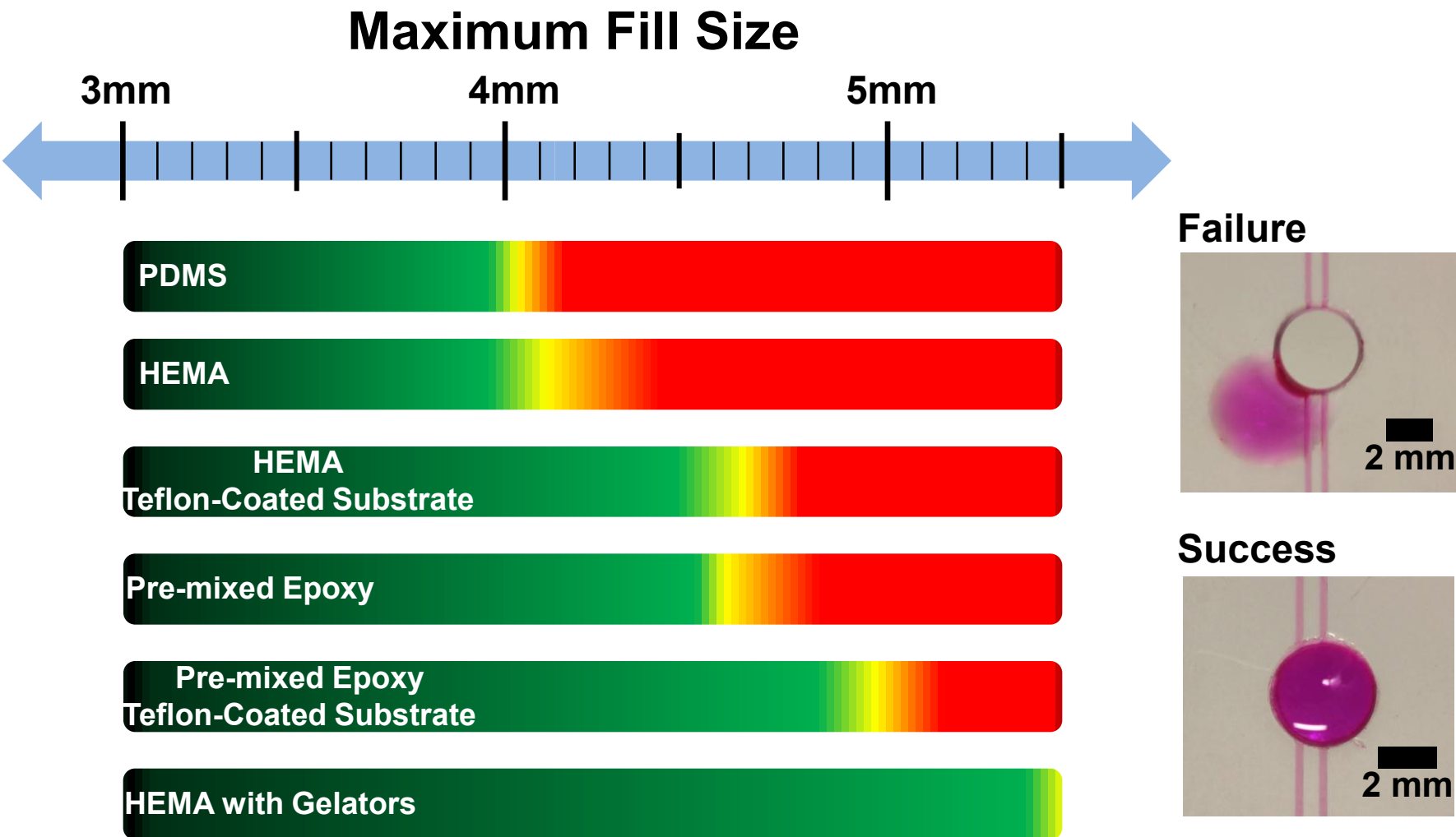
5.0 mm gap with bi-phase resin



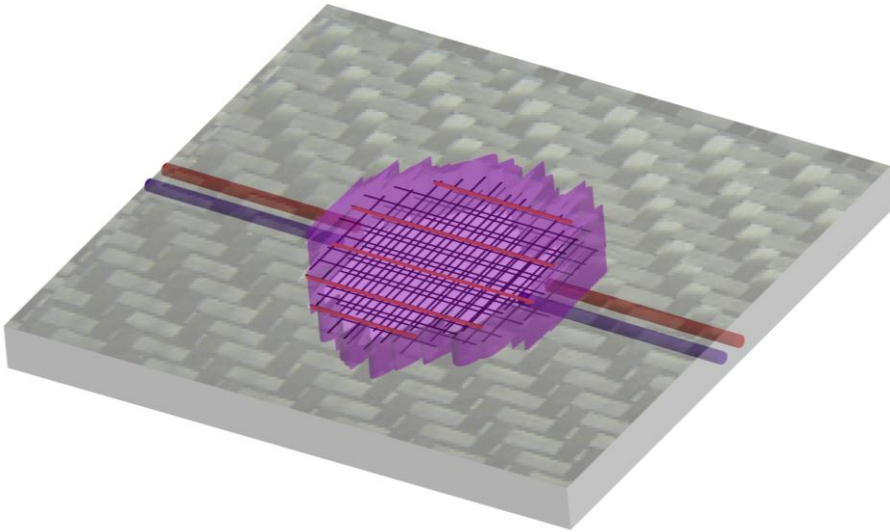
4.0 mm gap (PDMS healing system)



Damage Filling Results



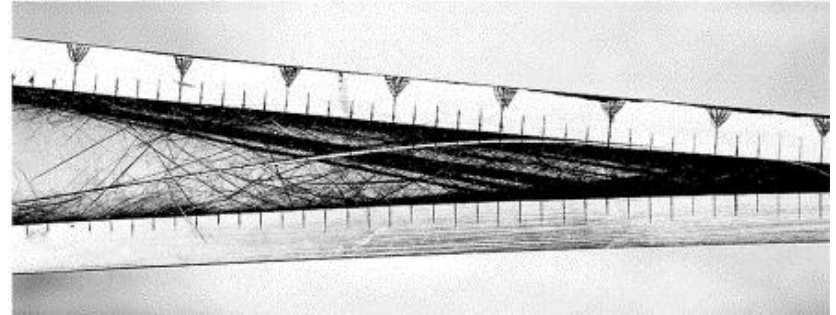
Multi-Scale Scaffold



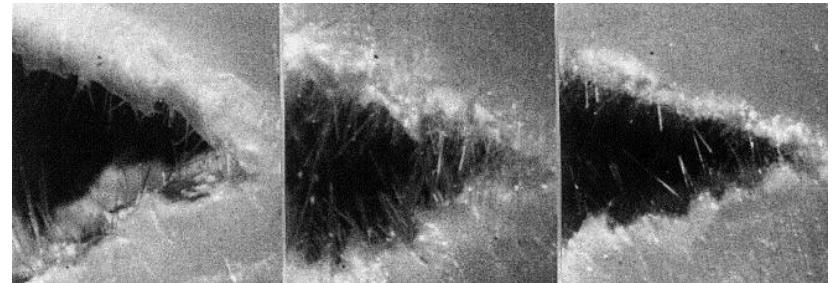
- **Concept:** Larger damage volumes can be regenerated using multiple scale scaffolds
- **Coarse Scaffold:** Fiber bridging/pullout
- **Molecular Scaffold:** Gel of bi-phase material

Fiber Bridging:

Carbon Fiber Reinforced Epoxy

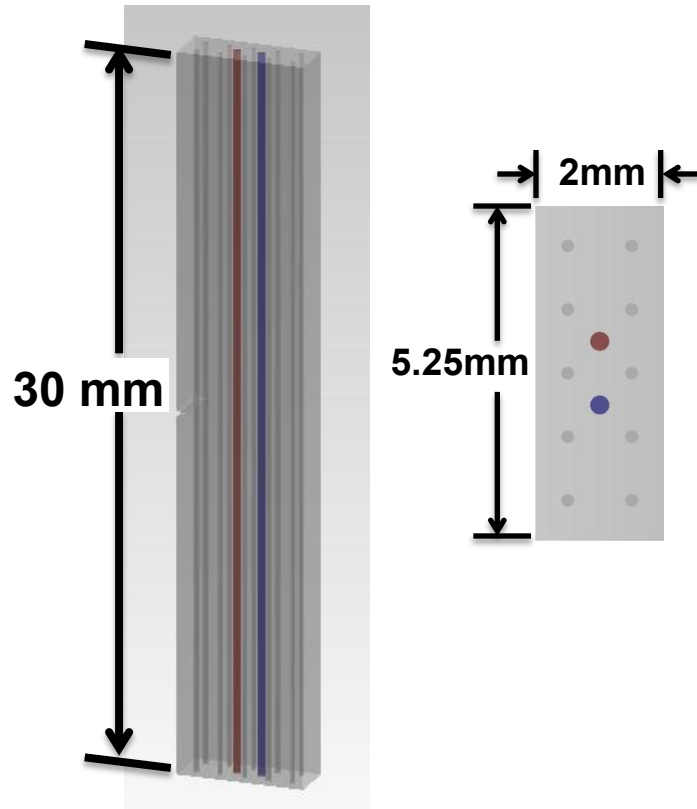


Short Glass Fiber Reinforced Nylon



Segregation of Damage Volume via Fiber Pullout

Specimen Geometry



Single Edge Notched Tension (SENT) 5x Speed

200 μ m Nylon
Monofilament

Notch

330 μ m
Channels

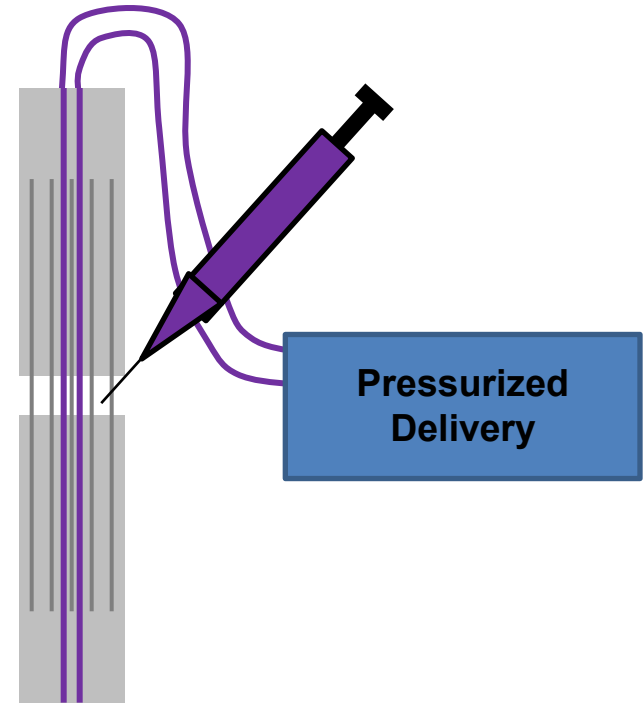
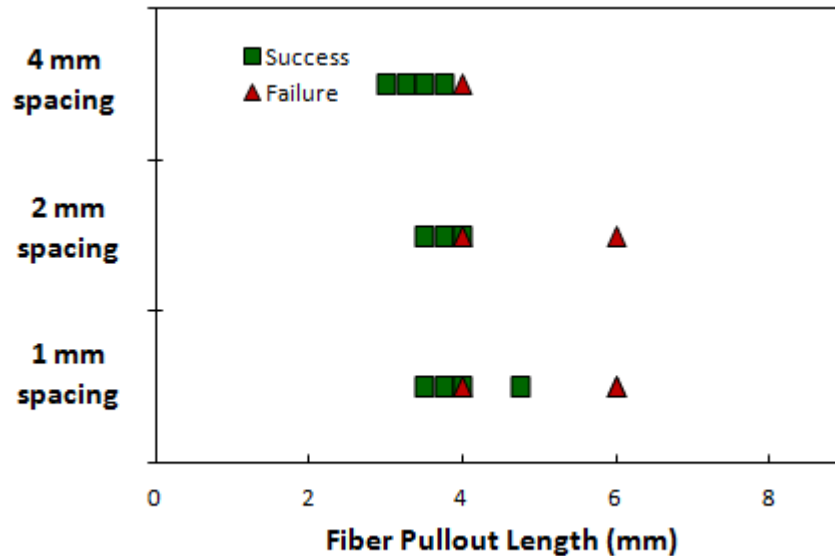
5 mm

2 mm

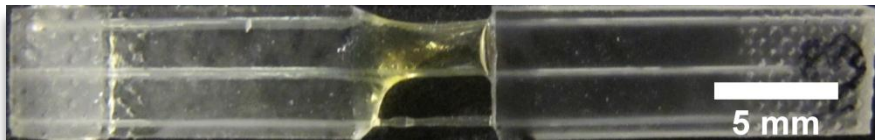
5 mm

Fill Testing of Bridged Region

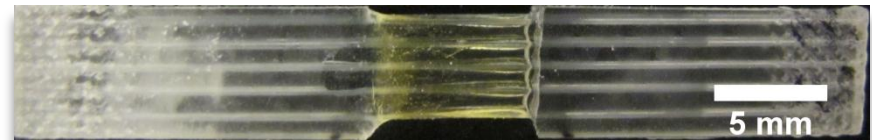
Vertical Orientation: Vajrota Premixed



Failure



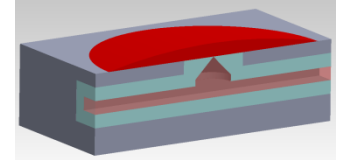
Success



Summary

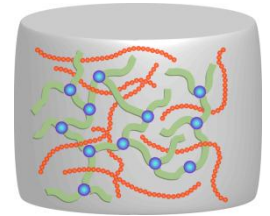
- **Embedded Valve Systems**

- Mitigates blockage of network for multiple healing cycles
- Autonomic delivery via pressure actuation



- **Bi-phase, 2-part Resin Chemistry**

- Tunable kinetics for each constituent
- Facile delivery of low viscosity, 2-part gel/resin system
- Exceeds surface tension limitations to fill large volumes



- **Regeneration of composite materials**

- Fiber bridging as vehicle for regenerative healing
- Combined with bi-phase system, multi-scale scaffolds

