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Can Nature Help Solve This Problem?

Biomimetic Adhesives for Infrastructure Repair

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The Heroes of Our Story

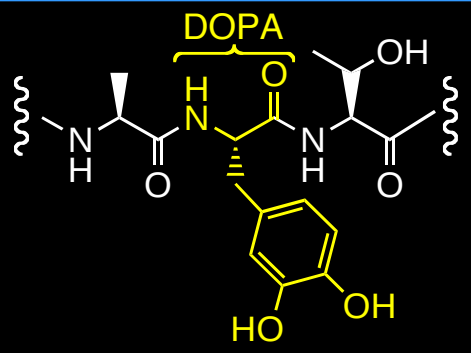
• mussels

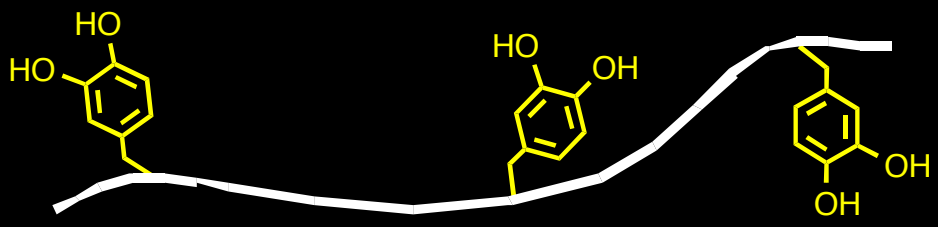
• barnacles

• oysters

- Reduce turbulence
- Deter predators
- Reproductive efficiency

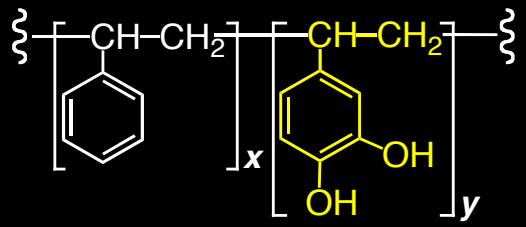
Reductionist Approach to New Materials



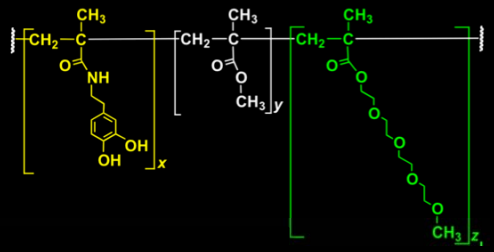


- Complex protein
- DOPA cross-linkable sidechains

- Simple polymer backbone
- Catechol groups



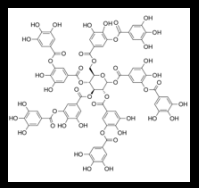
- poly(catechol-styrene)
- highest strength, dry & wet



- poly(catechol-MMA-OEG)
- tunable flexibility, modulus

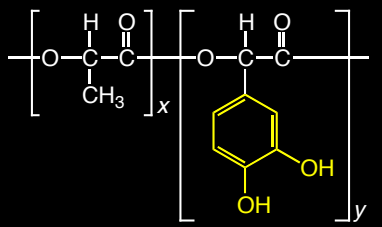
zein protein (corn)

+



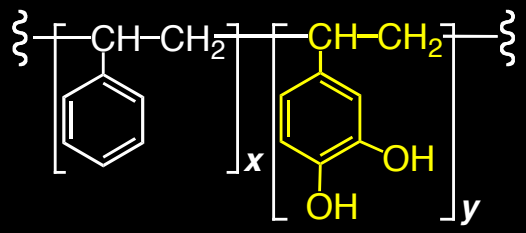
tannic acid (trees, coffee)

- zein-tannic acid
- bio-based, cheap



- poly(catechol-lactic acid)
- tunable degredation

Dry Adhesive Strengths on Etched Aluminum



- poly(catechol-styrene)
- optimized M_w, catechol %, formulation
- polymer + solvent + filler

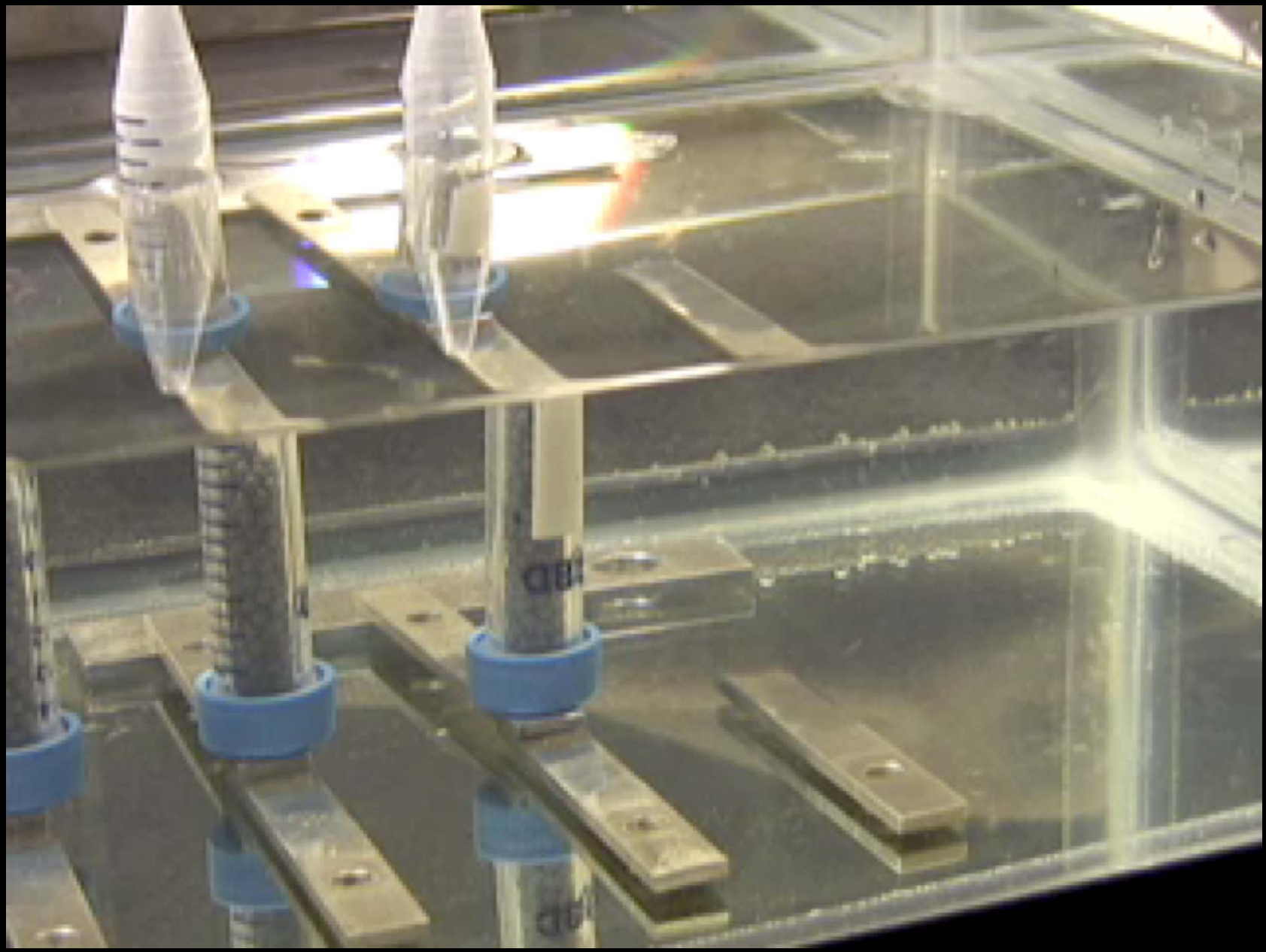
Gorilla Glue, urethane	3.3 (±0.8) MPa
Elmer's white PVA glue:	3.8 (± 0.6) MPa
Super Glue, cyanoacrylate	5.0 (± 0.7) MPa
Epoxy glue, Loctite Quick Set	18 (± 2) MPa
Our biomimetic copolymers:	11.0 (± 0.5) MPa

Dry Adhesion

	etched aluminum	sanded steel	red oak	Teflon
				
Elmer's Glue (polyvinyl acetate)	3.8 ± 0.6	7 ± 1	11 ± 2	0.48 ± 0.07
Loctite Super Glue (cyanoacrylate)	5.0 ± 0.7	7 ± 1	9 ± 2	0.7 ± 0.2
Loctite Quick Set (epoxy)	18 ± 2	18 ± 2	15 ± 2	1.0 ± 0.1
biomimetic polymer	11.0 ± 0.5	10 ± 1	6.0 ± 0.5	0.23 ± 0.08

- High performance versus commercial products

Underwater Adhesion Testing



Underwater Performance Versus Commercials

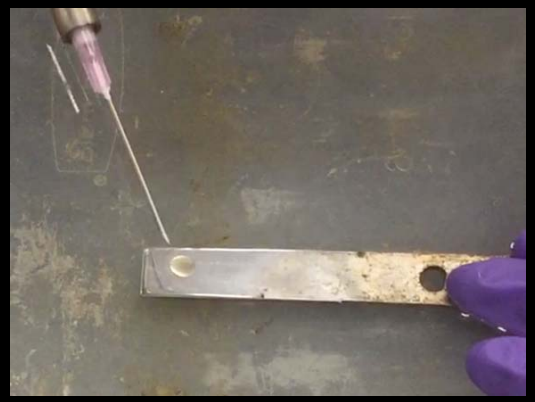
	polished aluminum	etched aluminum	sanded steel	red oak	PVC	Teflon
						
Gorilla Glue (urethane)	0.7 ± 0.1	0.4 ± 0.2	0.5 ± 0.1	0	3.0 ± 0.6	0
Mr. Sticky's (epoxy)	1.0 ± 0.3	0.2 ± 0.1	0.4 ± 0.1	0	3.0 ± 0.6	0.10 ± 0.08
North Sea Resin (acrylic)	0.3 ± 0.1	0	0.2 ± 0.1	0	0	0
Marine Loctite (epoxy)	0.6 ± 0.3	0	0.2 ± 0.1	0	2.0 ± 0.5	0
3M Marine (urethane)	0.2 ± 0.1	0.4 ± 0.2	0.5 ± 0.1	0	3.0 ± 0.6	0
biomimetic polymer	3.0 ± 0.4 *stronger*	0.2 ± 0.1 *same*	0.10 ± 0.02 *weaker*	0.2 ± 0.1 *stronger*	0.4 ±0.1 *weaker*	0.3 ± 0.1 *stronger*

- High performance versus commercial products

Formulation for Practical Use

Underwater lap shear on polished aluminum

chloroform
(beads up, rolls away)



1.3 ± 0.5 MPa

dichloroethane/dimethylformamide
(wets well, persists on
slanted substrates)

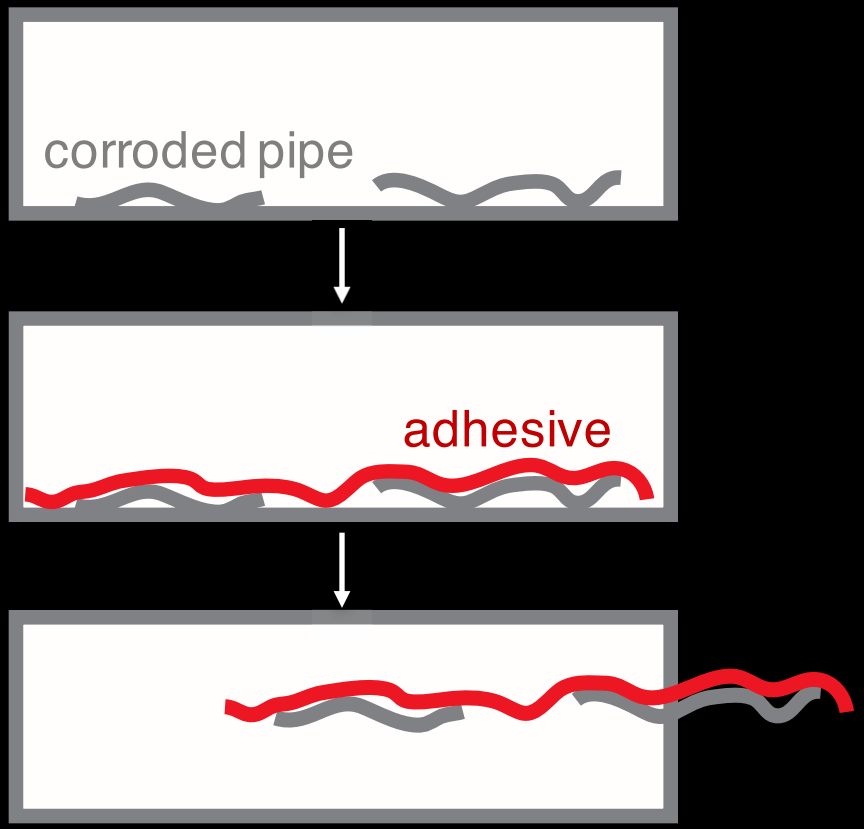
0.29 ± 0.05 MPa

- DCE/DMF has lower adhesion than $CHCl_3$, but is easier to work with
- This lower adhesion is still higher than most commercial glues

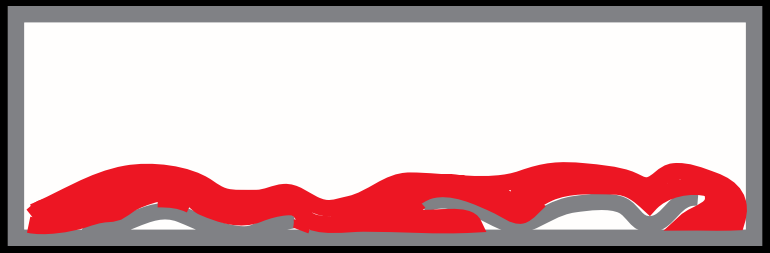
- Formulation work is straigthforward, but needs to be done.

Bonding Without Surface Cleaning?

- Bonding to degrading surfaces may lose the adhesive
- Perhaps we can reach the underlying surface



Potential alternative:

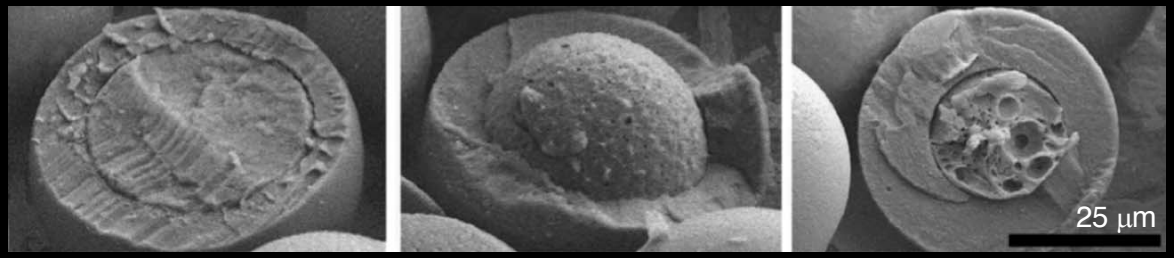


- Current epoxies may be too viscous
- Tailor properties as needed

- We have flexibility in formulation
- Can tune viscosity, etc. as needed
- Change polymer concentration, add fillers, etc.

Cross-Linking, Encapsulation, Formulation

- Two part adhesive system can make a gel, rapid curing
- Oxidants can cross-link polymer and cure the adhesive
- $(Bu_4N)(IO_4)$, periodate, is a good example, Fe^{3+} salts, too



Park and Yeo, Encyl. Pharm. Tech., 2007, p. 2315

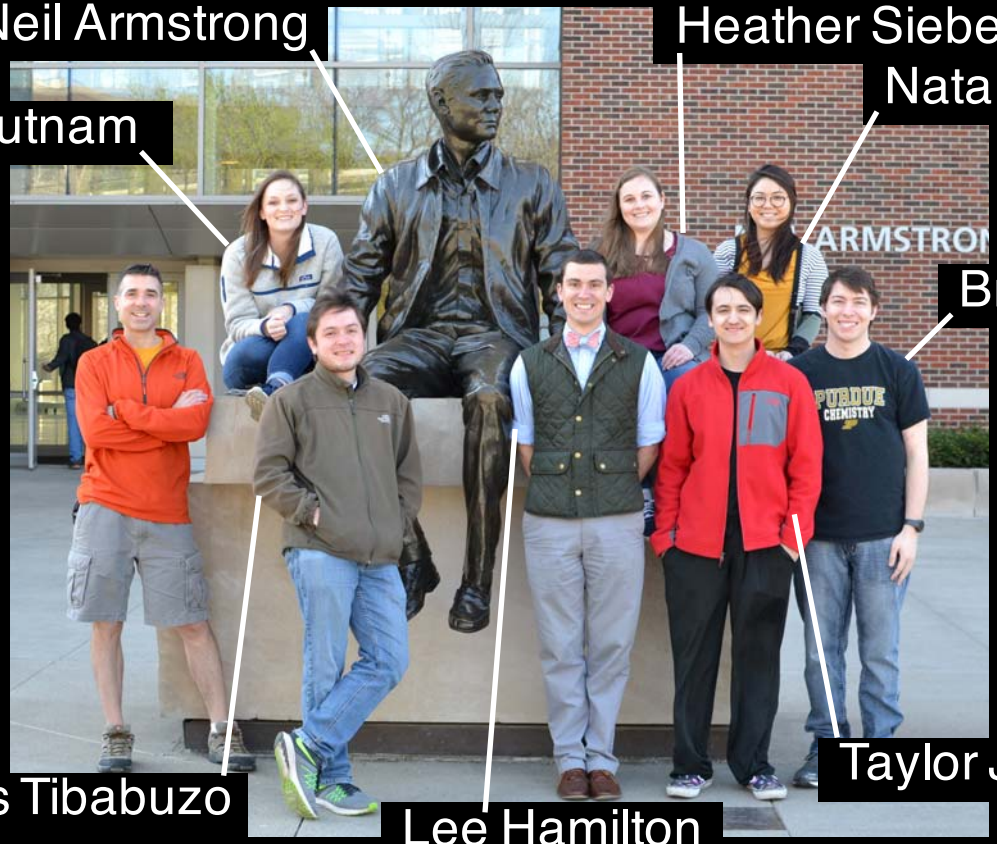
- Encapsulate oxidant in particle, break open to cure
- Not tried yet, but could work
- How to break open? How to fill? How to formulate?

Conclusions and Future Outlook

- Biomimetics yields high performance adhesives
- Hydrophobicity and wet bonding may help with pipelines
- Many variables available to change formulations

- Define ideal adhesive properties for pipeline repair
- Develop new formulations accordingly
- Test and reformulate

Acknowledgments



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