RECLAMATION

Managing Water in the West

Update on Evaluation of New Coating Technologies for Mitigation of Zebra/Quagga Mussel Colonization

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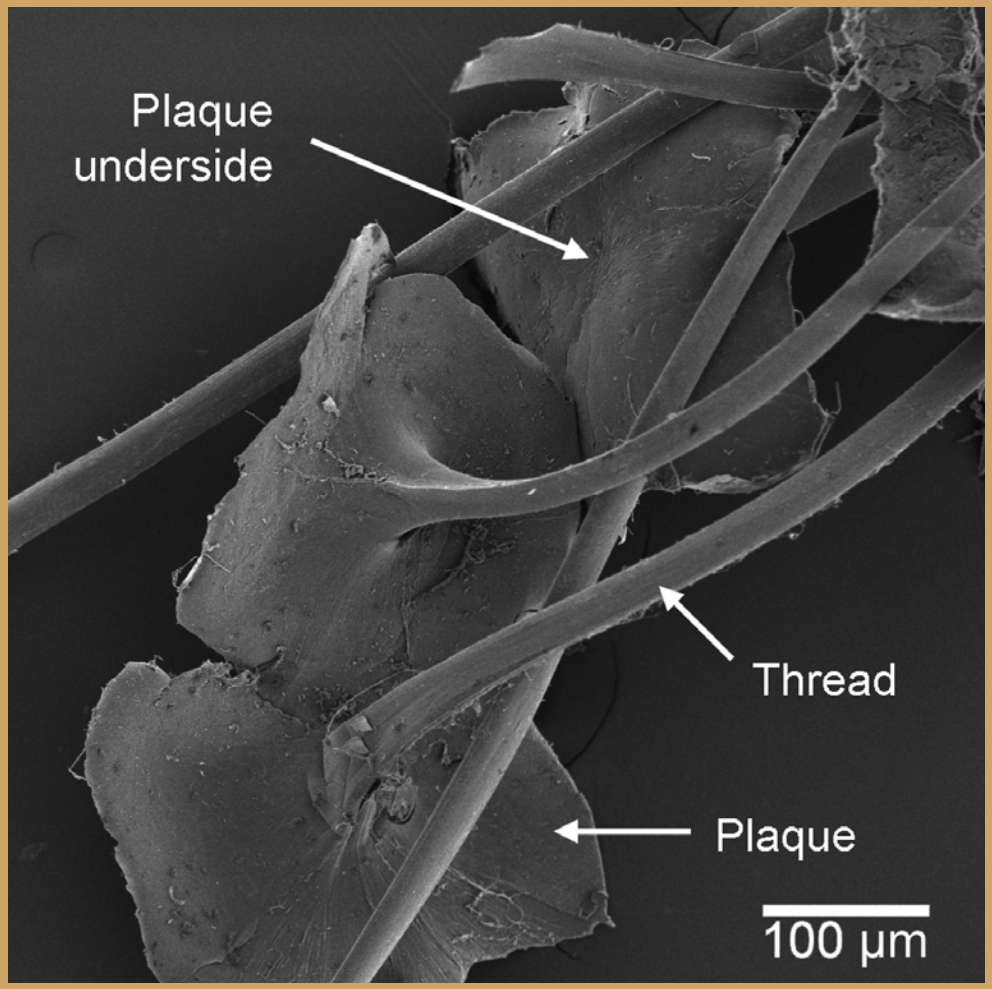
PREVIOUS LONG TERM STUDIES ON FOUL RELEASE COATINGS

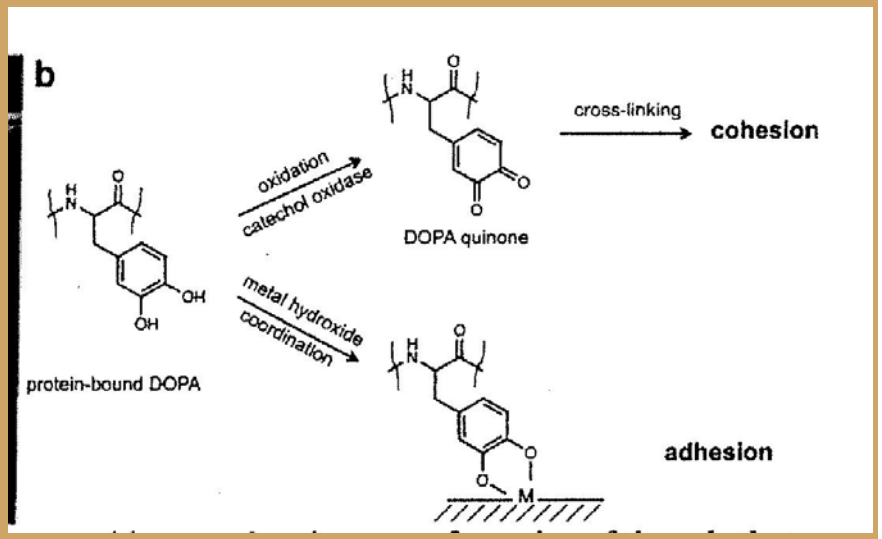
- Ontario Hydro
  - 8 year long test silicone foul release coatings performed well, some blistered and delaminated
  - Zebra mussels did not attach to silicone oil free FRC's
- Long Island Power Company
  - 8 year long test silicone foul release coatings performed well, some blistered and delaminated
  - Barnacles attached to the surfaces, but blue mussels did not attach to silicone oil free FRC's
- Army Corps of Engineers
  - Silicone FRC's performed well

MUSSEL ADHESION MECHANISM



Gilbert, 2010

3,4-dihydroxyphenylalanine (DOPA) bonds by hydrogen bonding, metal/metal oxide complex, and crosslinking

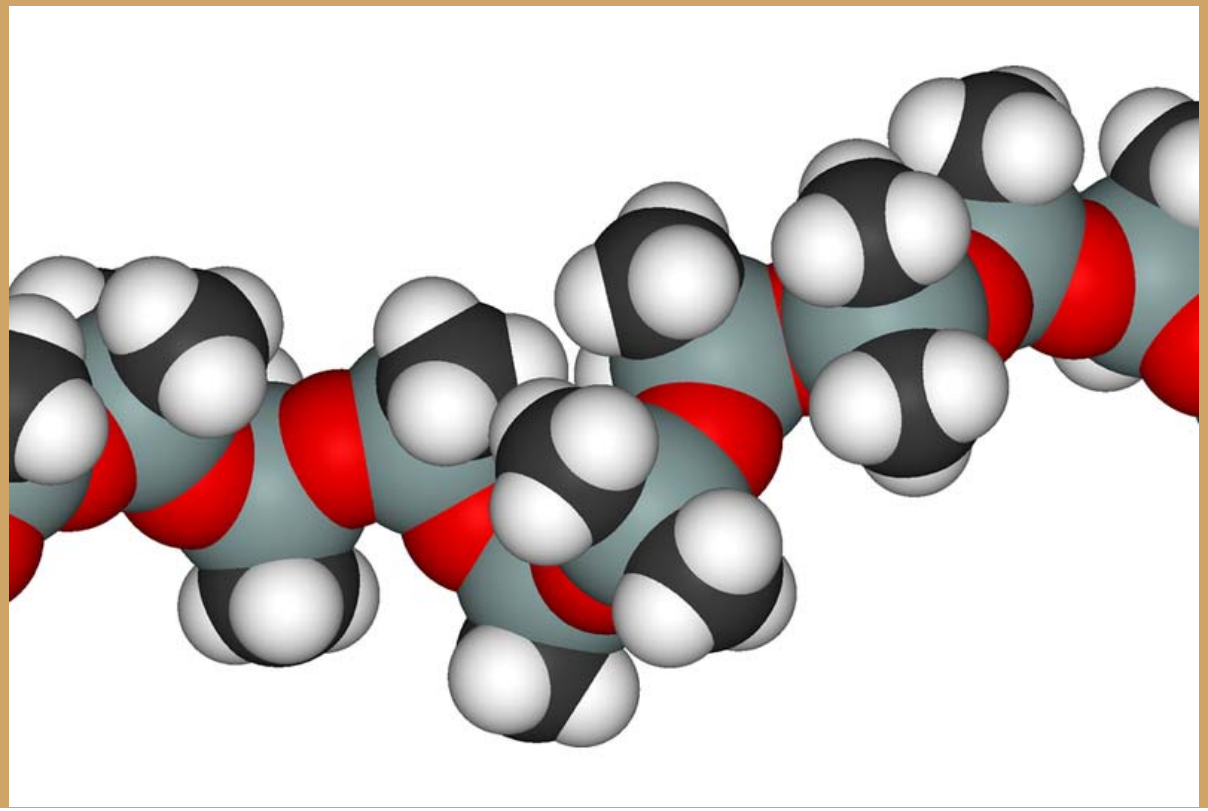


HYDROGEN BONDING THEORY

- Elements that form hydrogen bonds
  - Oxygen, nitrogen
  - Coatings that contain hydrogen bonding
    - Polyurethane, epoxy, acrylics, aspartics, polyurea, silicates (inorganic zinc), sol-gel, nylon, polyesters, etc.
  - Other ingredients; fillers and pigments
- Coatings that do not contain hydrogen bonding
  - Polydimethyl siloxane

HYDROGEN BONDING THEORY

- Polydimethyl siloxane
  - The methyl groups shield the oxygen from allowing hydrogen bonding



FIELD TESTING AT PARKER DAM

Quasi-static test location

Flowing (Dynamic) test location

FIELD TESTING PRODUCT DESCRIPTION

Coating ID	Generic Description	Dates Tested
FR-A1	Silicone - original	8/2008-Present
FR-A2	Silicone - optimized	3/2011-Present
FR-A3	Silicone - oil free	7/2012-Present
FR-A4	Silicone - tie coat	5/2010-11/2011
FR-B	Silicone – fluorinated Amphiphilic coating (hydrophobic and hydrophilic)	5/2008-Present
FR-C	Silicone	10/2009-Present
FR-D	Silicone	10/2009-Present

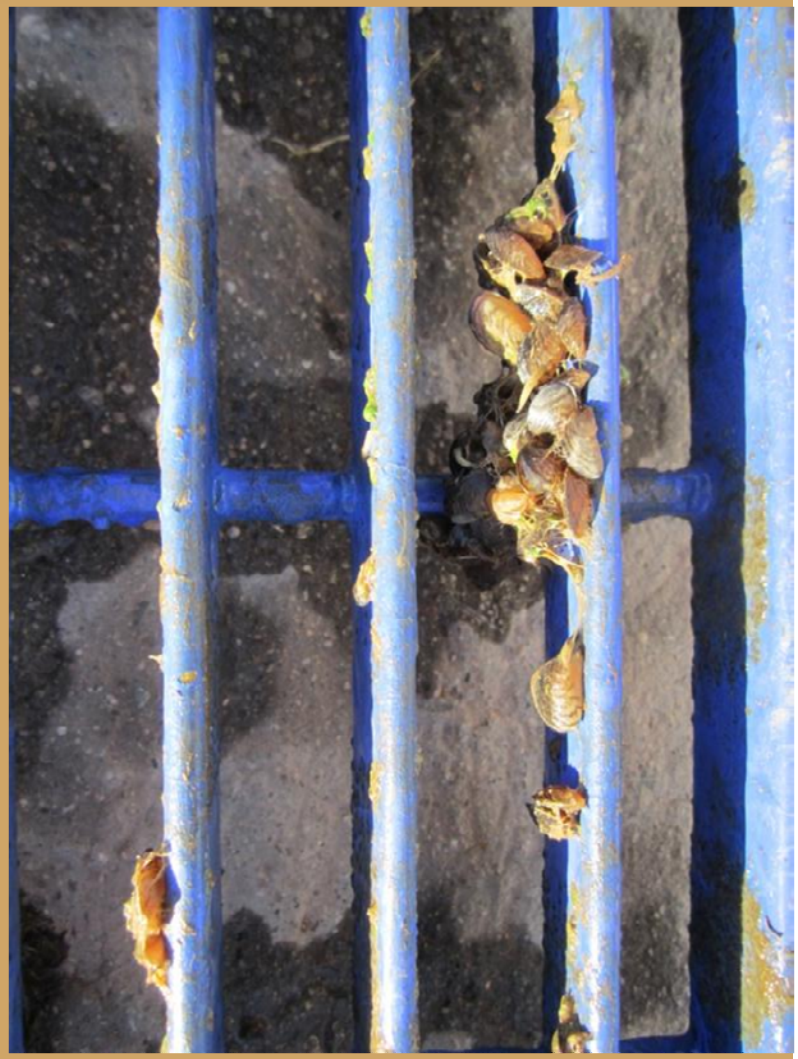
SILICONE FOUL RELEASE A-1 WHITE, EXPOSURE TIME 4.5 YEARS - DYNAMIC

SILICONE FOUL RELEASE A-1 WHITE, EXPOSURE TIME 4.5 YEARS - QUASI-STATIC

SILICONE FOUL RELEASE A-3 WHITE, EXPOSURE TIME 4 MONTHS - DYNAMIC

SILICONE FOUL RELEASE A-4 (TAN), EXPOSURE TIME 18 MONTHS - DYNAMIC

FLUORINATED SILICONE FOUL RELEASE B, EXPOSURE TIME 2 YEARS



SILICONE FOUL RELEASE COATING C, EXPOSURE TIME 3 YEARS

SILICONE FOUL RELEASE COATING D, EXPOSURE TIME 3 YEARS

STAINLESS STEEL
EXPOSURE TIME 1 YEAR AND 2 YEARS

RESULTS

Coating	Attached Mussels	Maximum Force to Remove a Single Mussel	Blockage of Grate in Flowing Water						
			Jan. 2010	May 2010	Nov. 2010	May 2011	Nov. 2011	May 2012	Nov. 2012
Polyamide epoxy	Yes	1.4 lbs				87%			
Stainless Steel	Yes	1.75 lbs				80%	100%	100%	
FR-A1	No	N/A	6.7%	8.9%	9.8%	8.4%	9.8%	0.0%	0.0%
FR-A2	No	N/A			0.0%	12.4%	0.0%	0.0%	0.0%
FR-A3	No	N/A							0.0%
FR-A4	Yes	0.25 lbs			36.6%	52.7%	30.1%		
FR-B	Yes	0.25 lbs	3.4%	24.4%	0.8%	1.9%	2.3%	2.3%	1.0%
FR-C	No	N/A	0.0%	9.8%	17.0%	0.1%	31.4%	4.7%	19.0%
FR-D	No	N/A	0.0%	1.1%	0.0%	16.4%	31.3%	4.0%	0.0%

DISCUSSION

Silicone Coatings

•Silicone based foul release coatings have been most successful in preventing mussel attachment in both quasi-static and dynamic conditions. They have very low attachment strengths of algae, bryozoans, and slime.

•These results are different than findings in the ocean, barnacles and tube worms still attach to silicone foul release coatings.

•It is believed the silicones work because the combination of low surface energy, low elastic modulus, and the lack of hydrogen bonding sites

•Durability continues to be a concern with silicone based foul-release coatings

DISCUSSION

Silicone Coatings Containing Hydrogen Bonding:

- Silicone based coatings, A-4 and B, contain low concentrations of hydrogen bonding sites. Thus allowed mussel attachment, but at very low attachment strengths
- System A-4 is a tie coat, designed to bond with epoxy and contains some oxygen and nitrogen
- System B is an amphiphilic coating that contains hydrophobic and hydrophilic domains
- It is believed that the mussels attach to these systems by hydrogen bonding

DISCUSSION

Silicone Foul Release Coatings without oil release agent

•Silicone oil free coating, System A-3 appears to give equivalent performance to the optimized formulation that contains silicone oil.

•Mussels do not attach to the PDMS coatings with or without silicone oil release agents, which strengthens the hydrogen bonding theory

•This finding contradicts results from the marine industry, silicone oil release agents are required to release barnacles easier

FUTURE RESEARCH AND NEEDS

- If mussels attach by hydrogen bonding, then it might be possible to increase the mechanical properties of the silicones without jeopardizing the performance
- For industrial maintenance, we need to be able to handle the infrastructure without damaging the coatings otherwise the mussels will still attach on the damaged areas
- Need to be able to apply to small diameter piping that is already in place. Possible options, robotic spin coaters, in-situ liners, or applications to HDPE

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REFERENCES

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