The Effect of Iron Deposition on Mussel Thread Strength

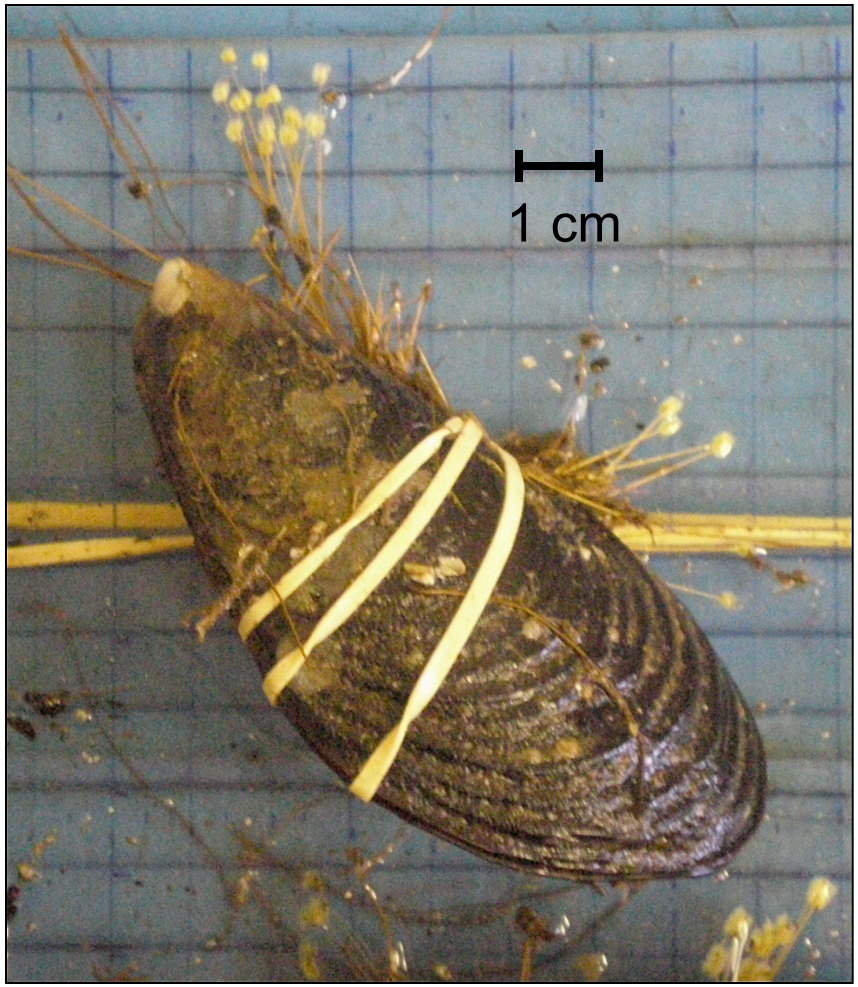
Julia Callender, YerPeng Tan

Dr. Herbert Waite, Molecular, Cellular and Developmental Biology

EUREKA Program, University of California Santa Barbara

August 25, 2011

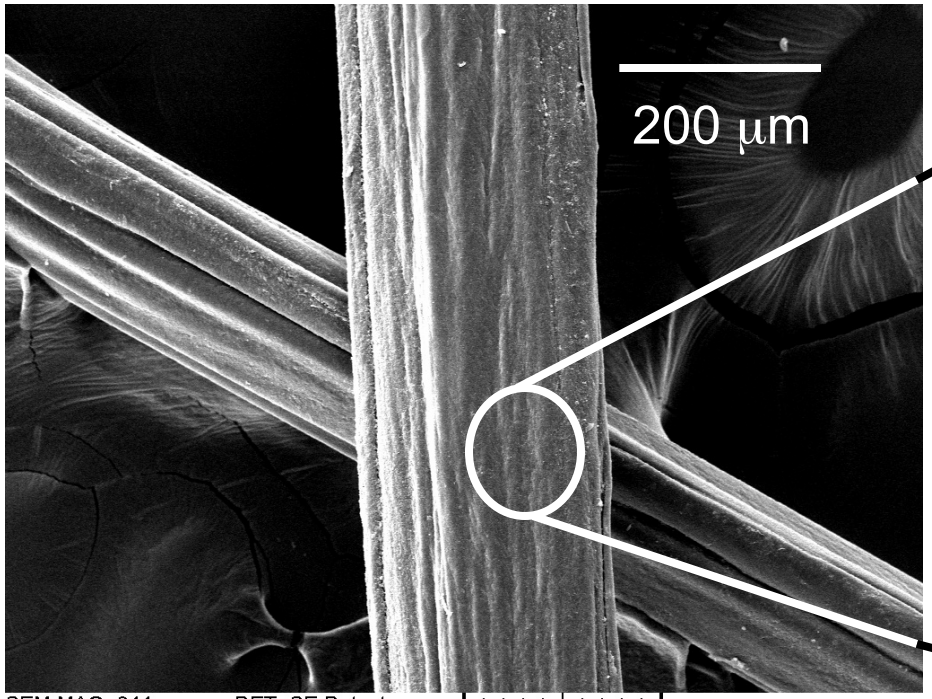
Mytilus californianus California Mussel



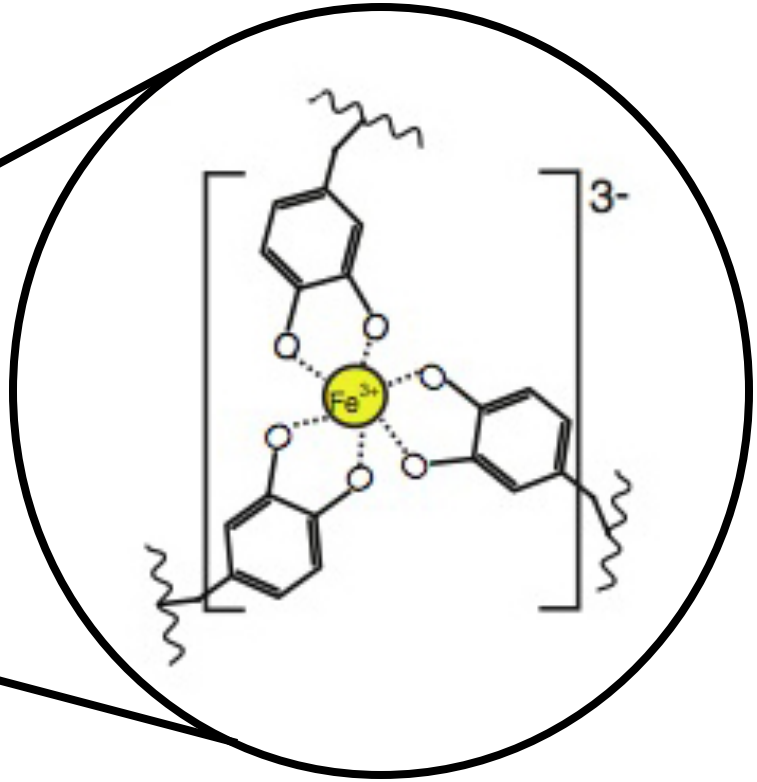
Byssal threads are used to attach to substrates in the wave-swept intertidal zone.

Properties: strong yet extensible, exhibit recovery following deformation.

Protein-Metal Crosslinks: Dopa-Fe^{3+}



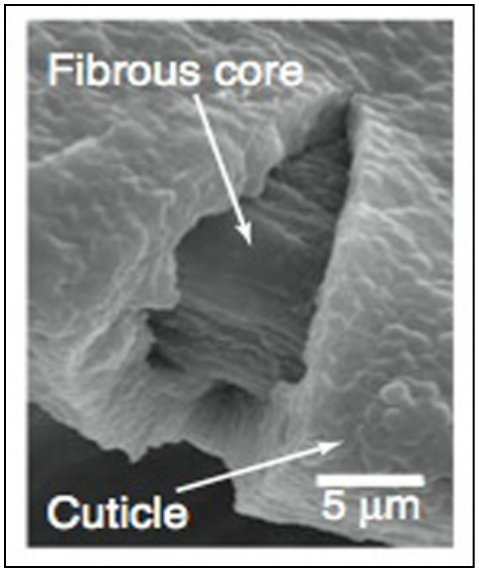
SEM image of byssal threads



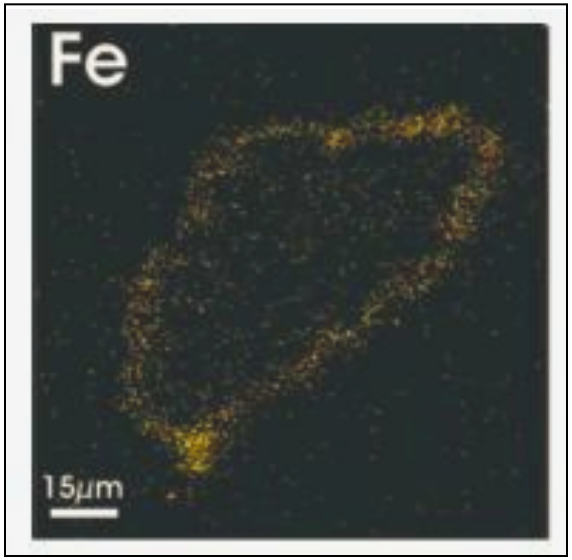
[1.] 3,4-dihydroxyphenylalanine (Dopa) side chains cross-linking with Fe^{3+} ion

[1]. Iron-Clad Fibers: A Metal-Based Biological Strategy for hard Flexible Coatings. M. J. Harrington, Admir, Masic, Niels Holten-Andersen, J. H. Waite, and Peter Fratzl. *Science* 9 April 2010: 328 (5975), 216-220.

Byssal Thread Structure



[1.] SEM image of byssus core and cuticle

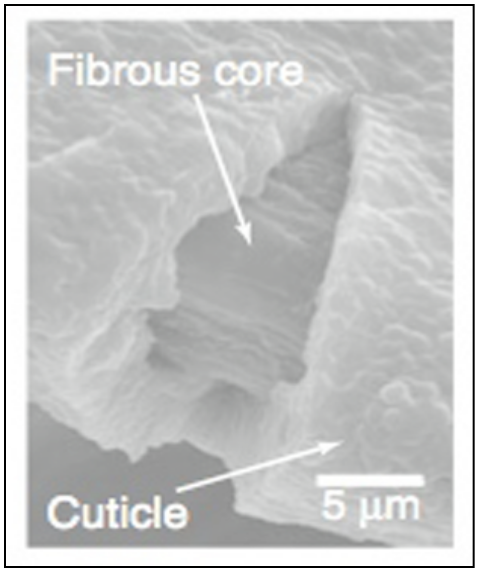


[2.] SIMS image of iron localization in thread cross section

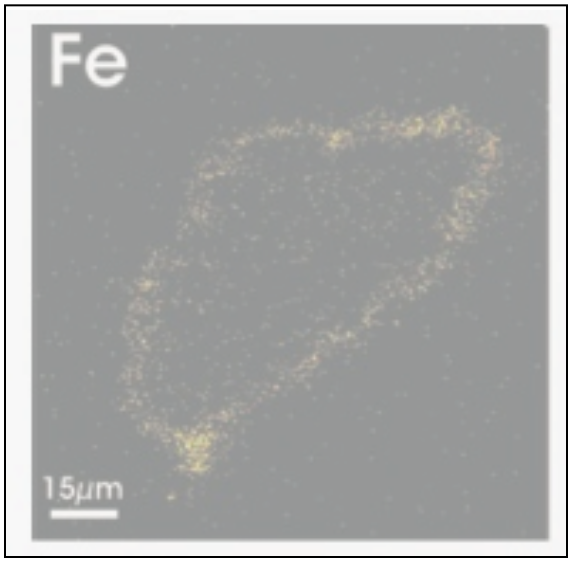
[1]. Iron-Clad Fibers: A Metal-Based Biological Strategy for hard Flexible Coatings. M. J. Harrington, Admir, Masic, Niels Holten-Andersen, J. H. Waite, and Peter Fratzl. *Science* 9 April 2010: 328 (5975), 216-220.

[2]. Metals and the Integrity of a Biological Coating: The Cuticle of Mussel Byssus. Niels Holten-Andersen, Thomas E. Mates, Muhammet S. Toprak, Galen D. Stucky, Frank W. Zok and J. Herbert Waite. *Langmuir* 2009: 25 (6), pp 3323-3326.

Byssal Thread Structure



[1.] SEM image of byssus core and cuticle



[2.] SIMS image of iron localization in thread cross section

Soak threads in solutions of varying $FeCl_3$ concentration → Mechanically Test Threads → Use chemical visualization methods to view localization of iron in threads

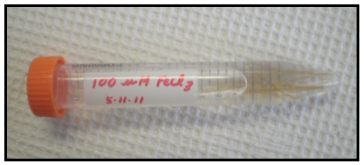
[1]. Iron-Clad Fibers: A Metal-Based Biological Strategy for hard Flexible Coatings. M. J. Harrington, Admir, Masic, Niels Holten-Andersen, J. H. Waite, and Peter Fratzl. *Science* 9 April 2010: 328 (5975), 216-220.

[2]. Metals and the Integrity of a Biological Coating: The Cuticle of Mussel Byssus. Niels Holten-Andersen, Thomas E. Mates, Muhammet S. Toprak, Galen D. Stucky, Frank W. Zok and J. Herbert Waite. *Langmuir* 2009: 25 (6), pp 3323-3326.

Mechanical tests: show correlation between $FeCl_3$ treatments and thread mechanics

Harvest threads from live mussels

Soak threads in solutions

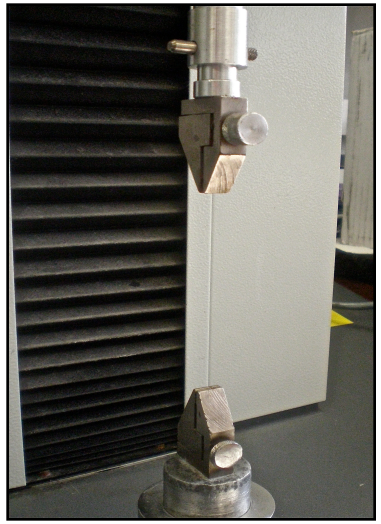


- 1 uM $FeCl_3$
- 10 uM $FeCl_3$
- 100 uM $FeCl_3$
- CH_3COONa Buffer (control)

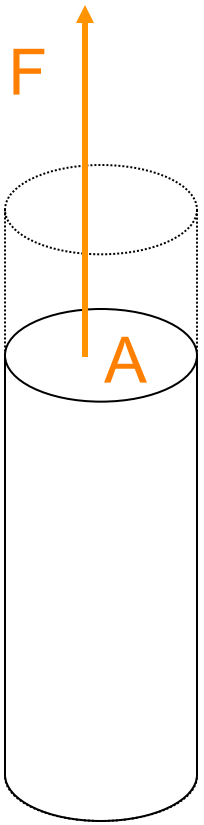
Soak 12-24 hours

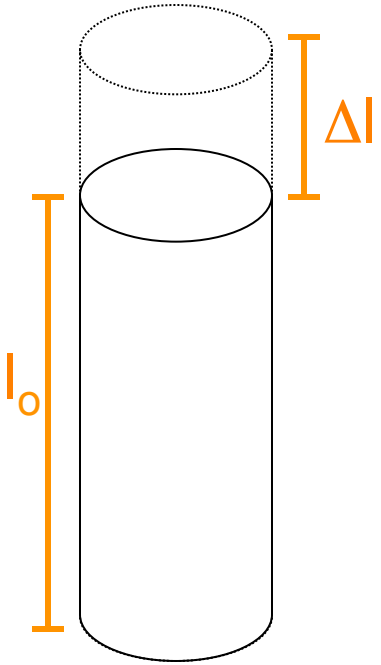
~12˚ C, 12-24 hr

Mechanical testing in Bionix 200 MTS machine, surrounded by sea water



Tensile tests calculate stress and strain

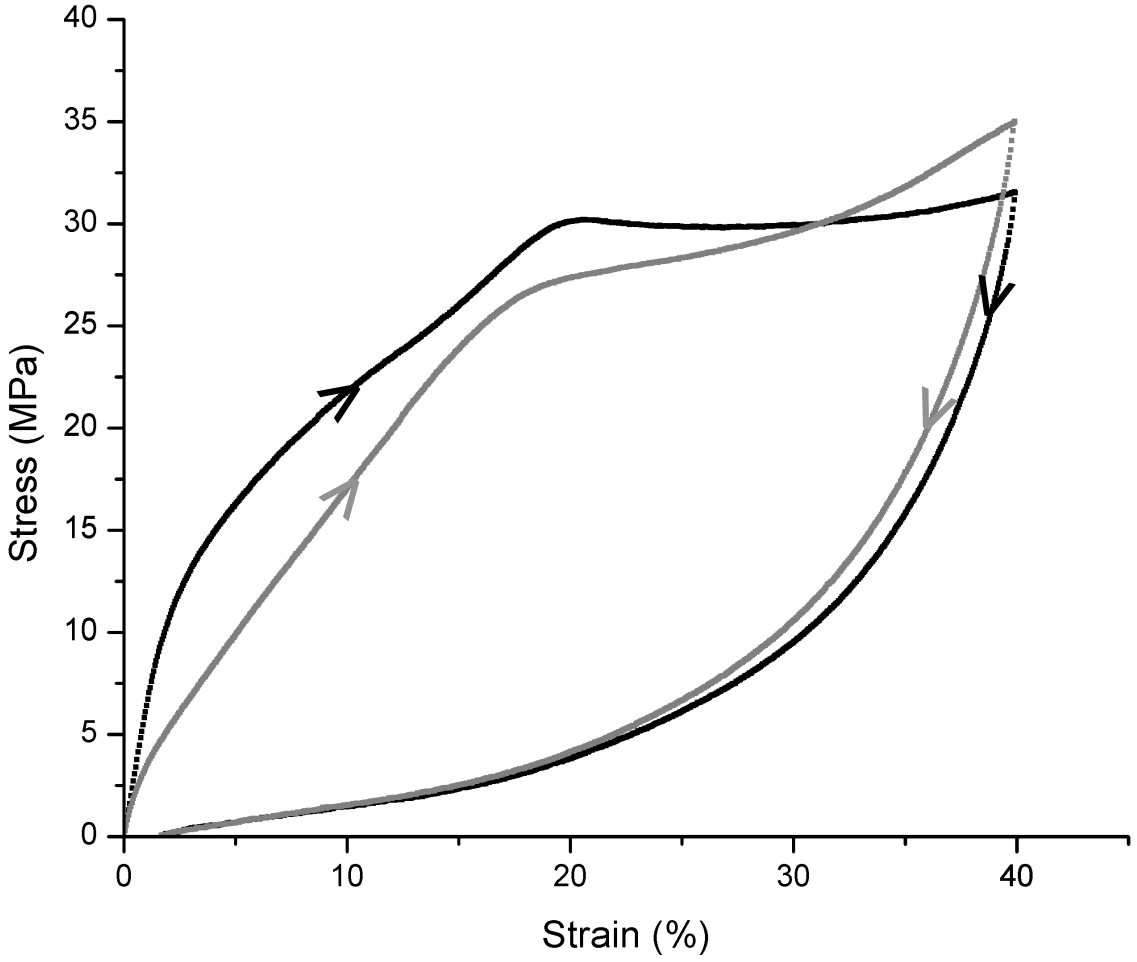




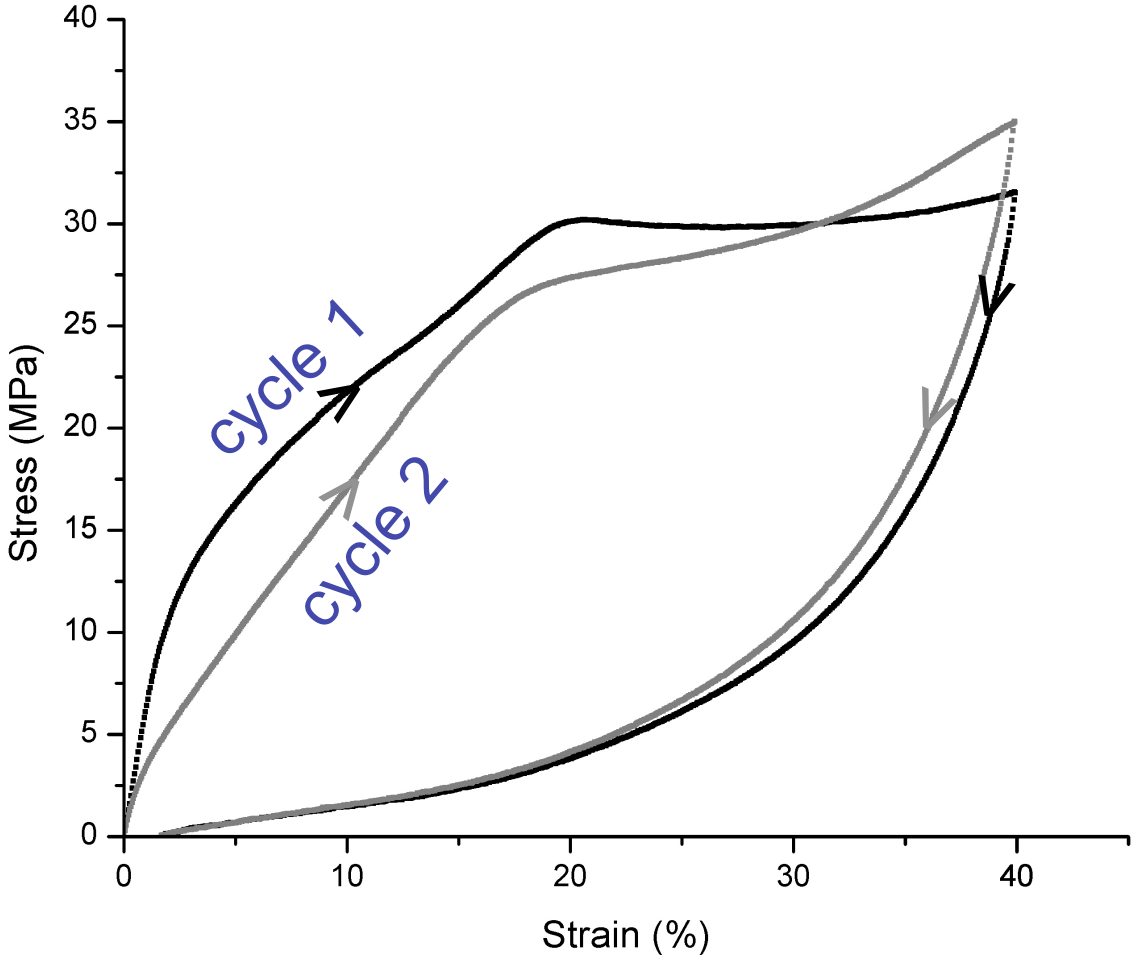
$$Stress = \frac{F}{A}$$

$$Strain = \frac{\Delta l}{l_o}$$

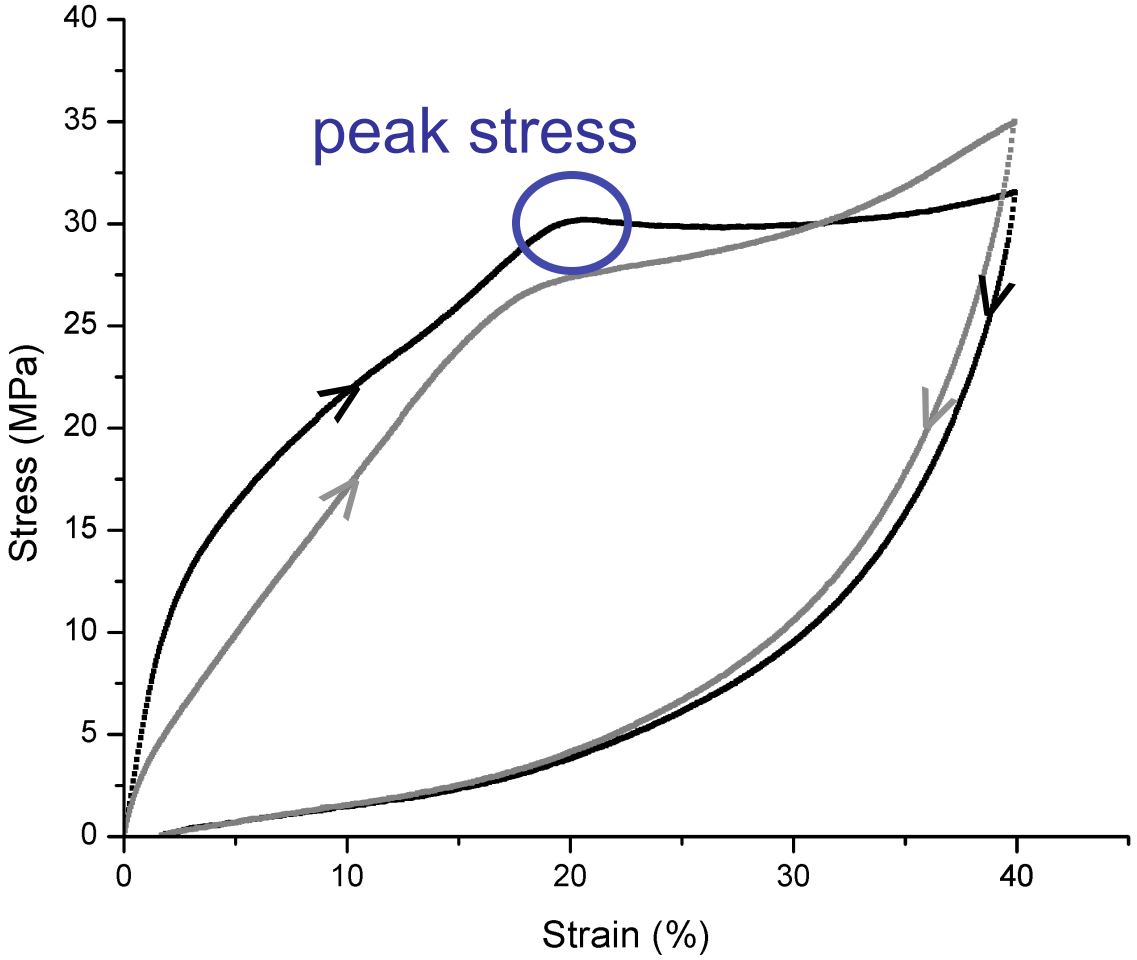
Mechanical tests: tensile testing of whole threads



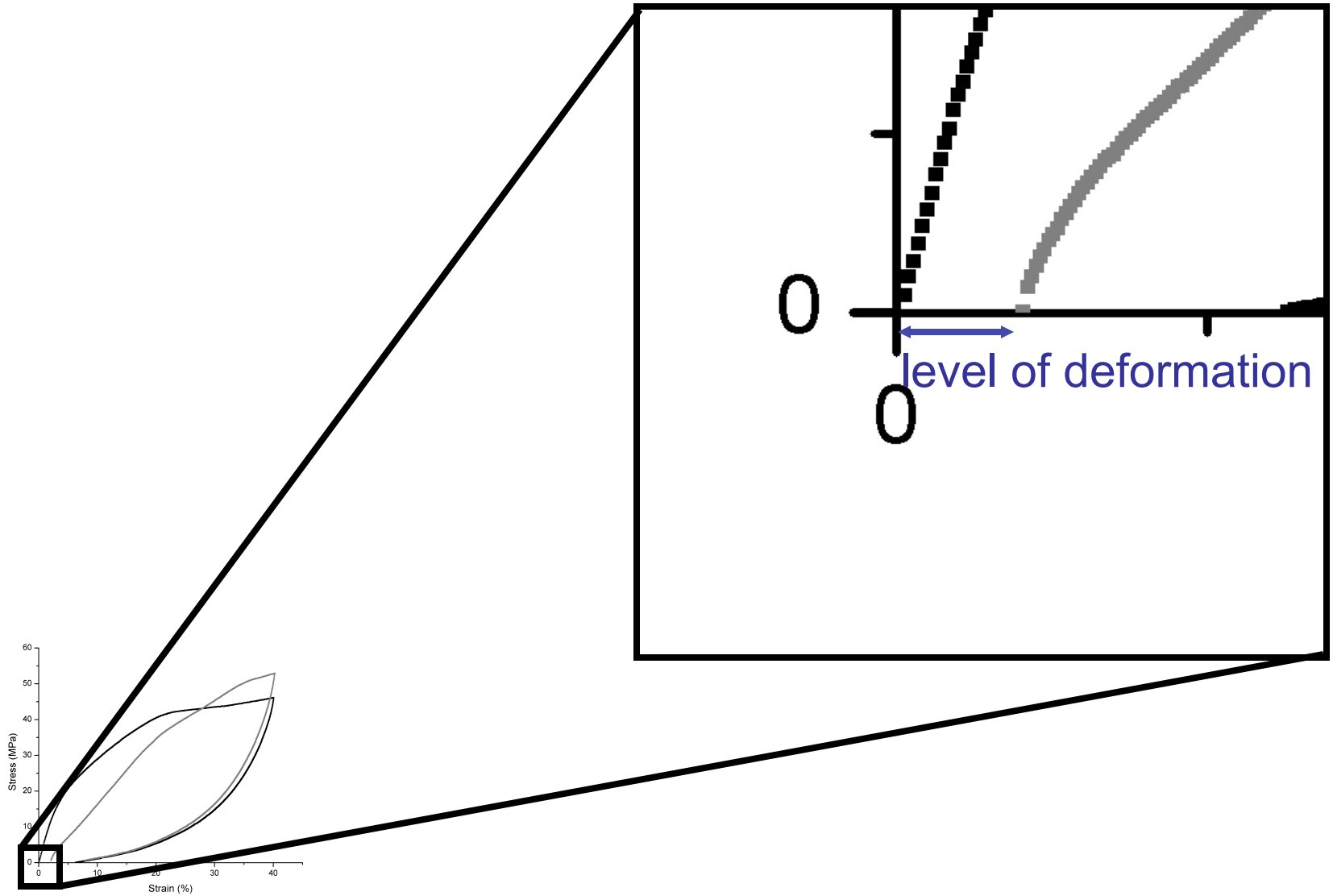
Mechanical tests: tensile testing of whole threads



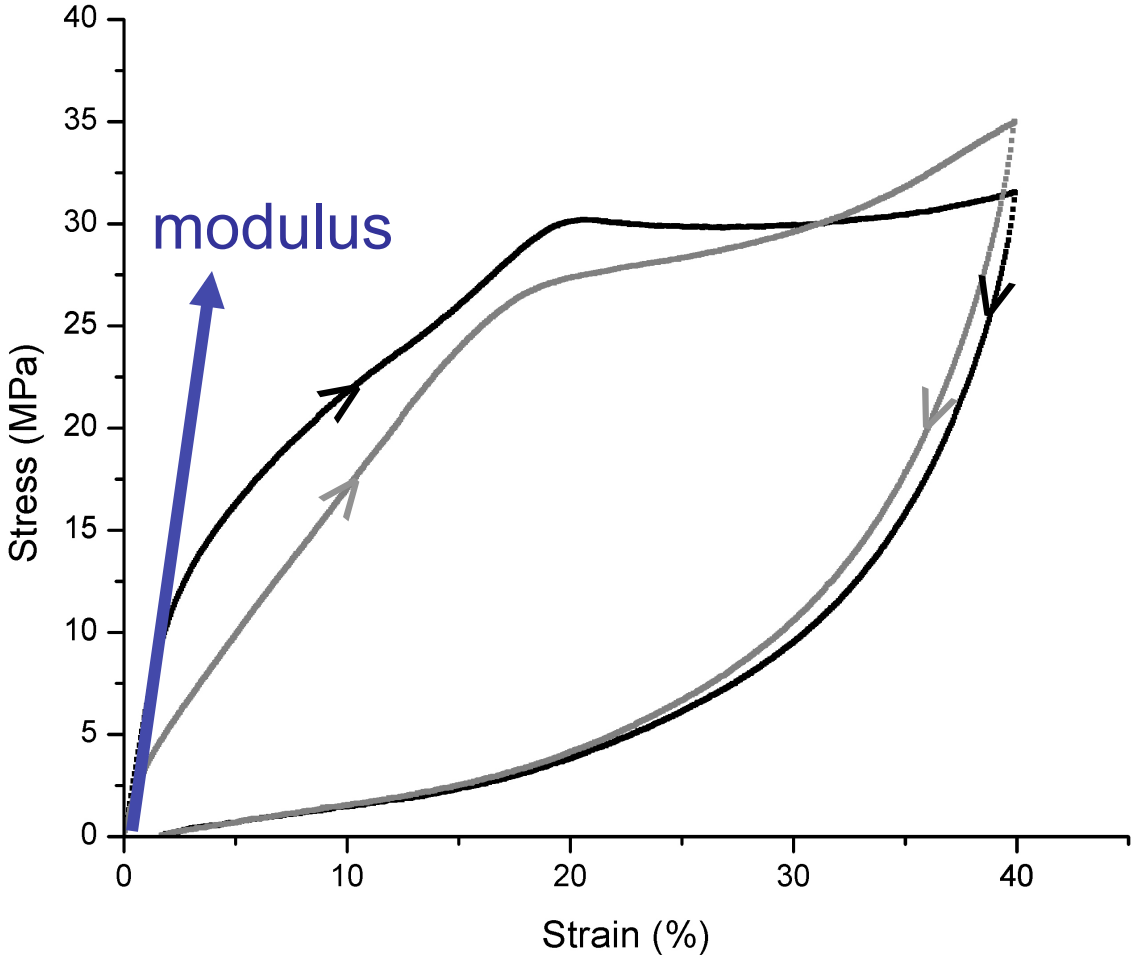
Mechanical tests: tensile testing of whole threads



Mechanical tests: tensile testing of whole threads

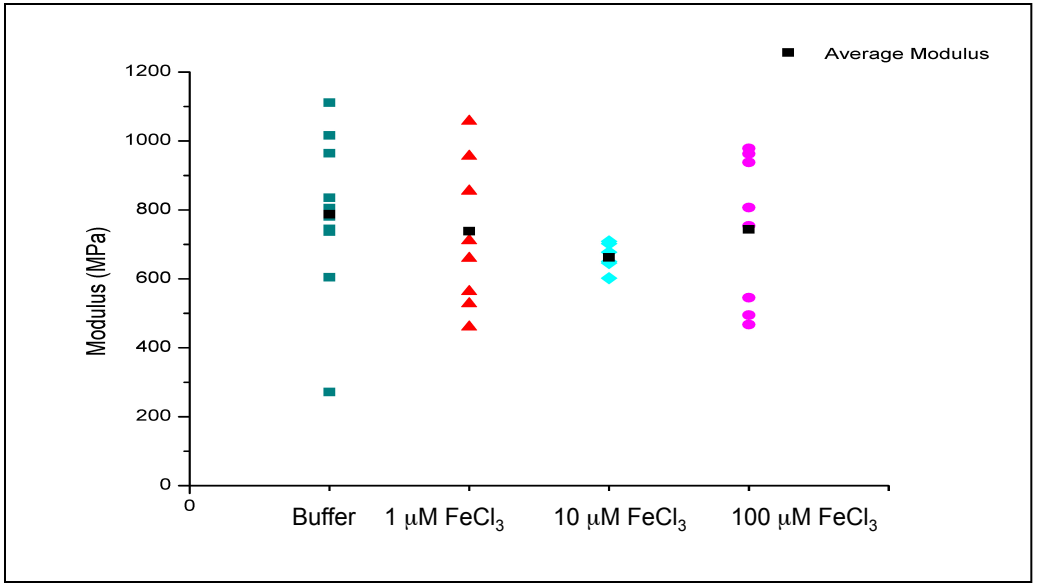


Mechanical tests: tensile testing of whole threads

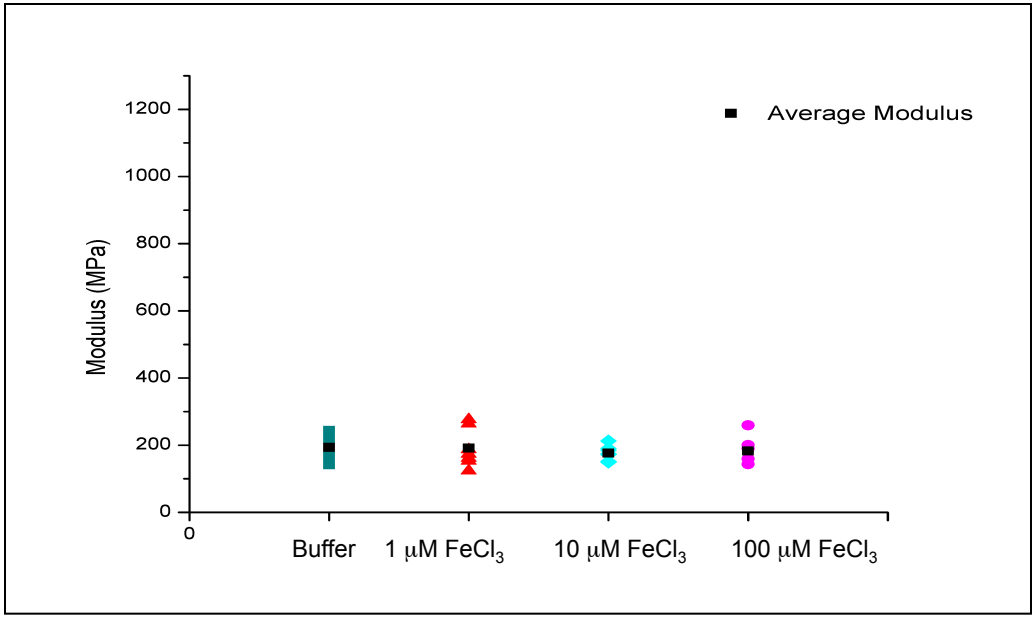


Results: Modulus

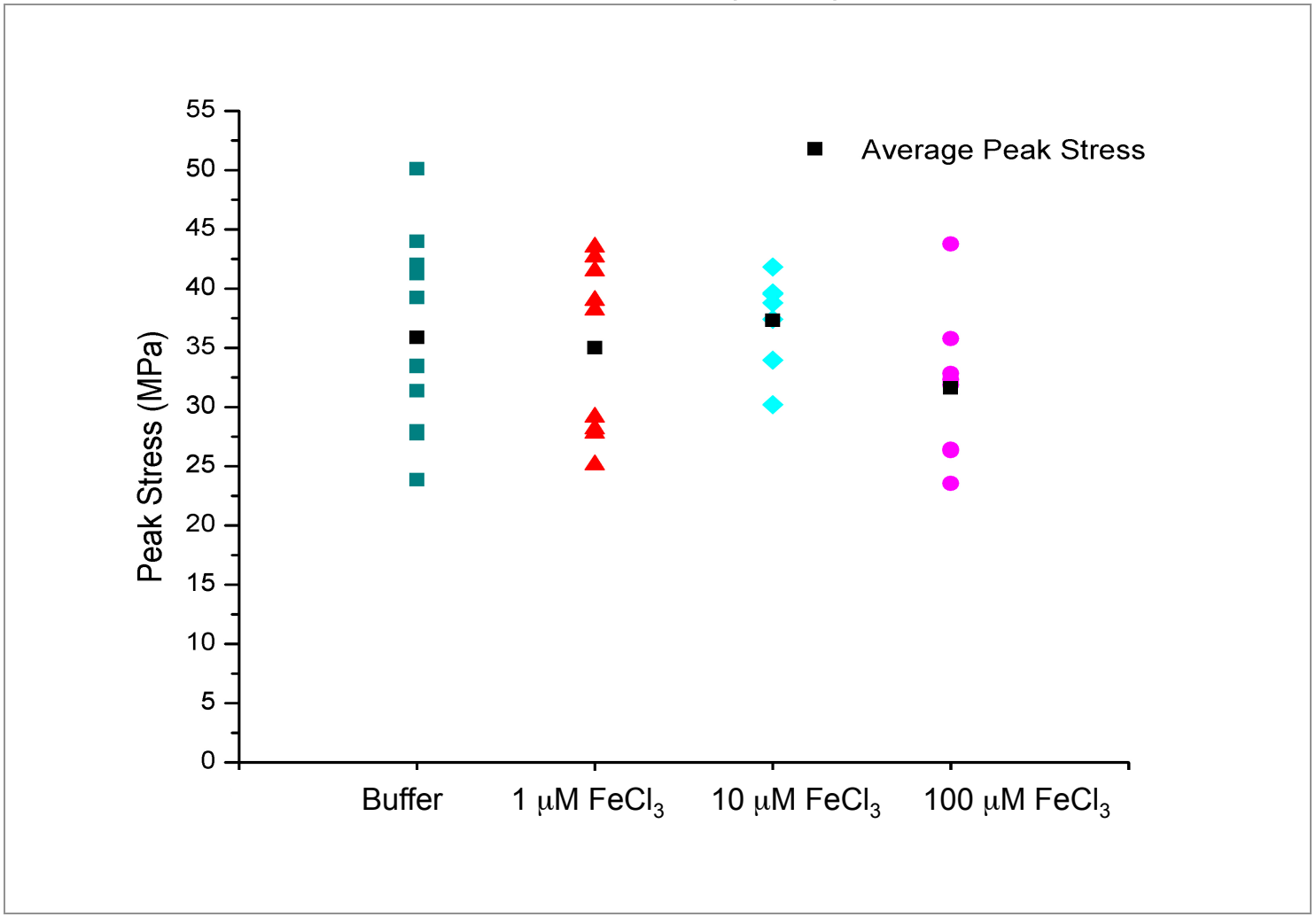
Modulus (First Cycle)



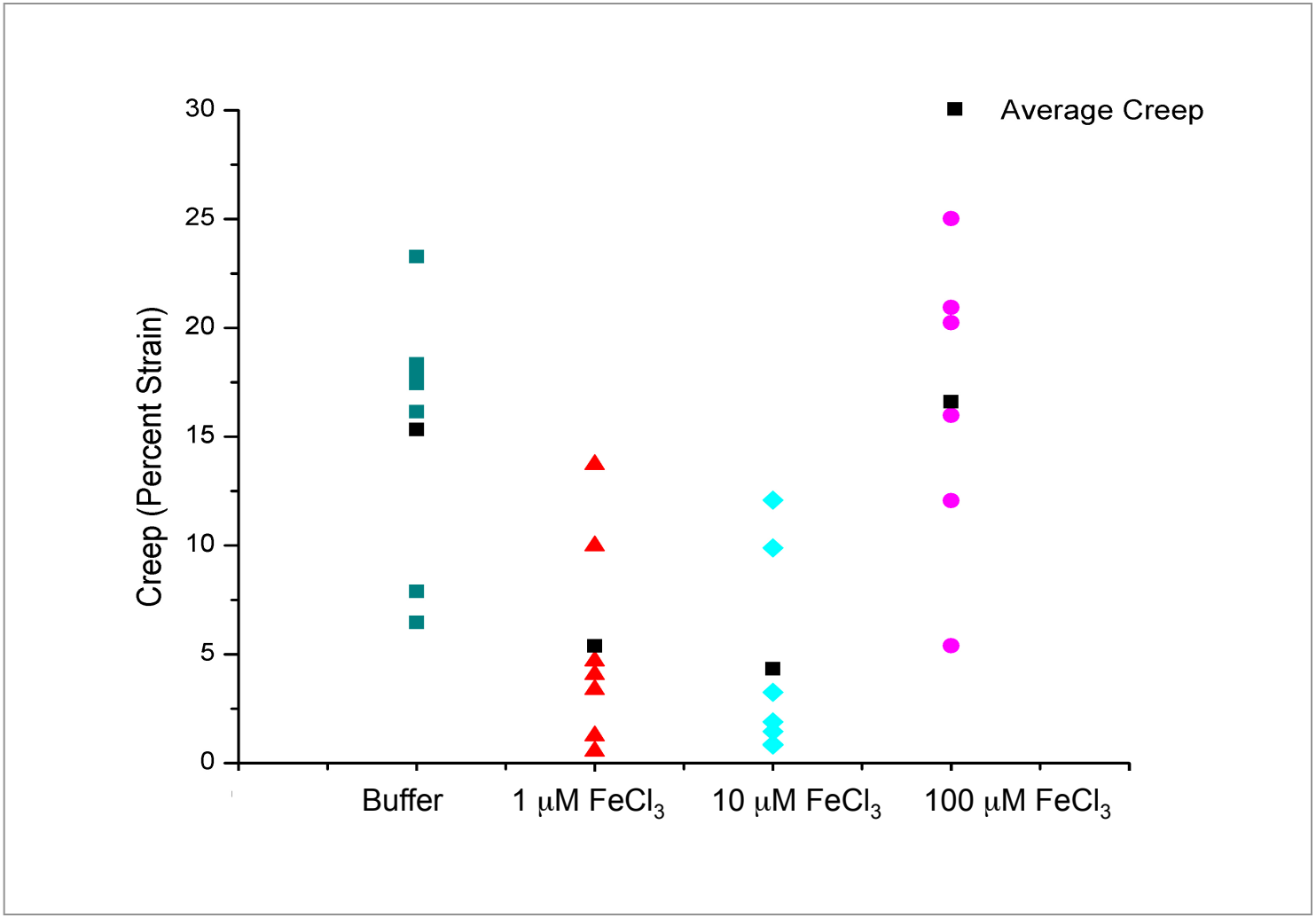
Modulus (Second Cycle)



Results: Peak Stress



Results: Creep



Effect of $FeCl_3$ treatments on thread mechanics

- Modulus: the data averages for both the first and the second modulus are not significantly different between iron treatments.
- Peak stress: the data averages are not significantly different between iron treatments.
- Level of deformation: the data averages for 1 and 10 μM $FeCl_3$ treatments are significantly different from the averages of the other treatments.

Is the iron bonding with the Dopa?

Energy Dispersive X-ray Spectroscopy (EDX)

Threads soaked in iron treatments, put through chemical analysis without being stretched:

Iron Treatment	Weight % Fe in sample	
	First spot on thread	Second spot on thread
Buffer	0.183	0.455
1 μM $FeCl_3$	0.106	0.267
10 μM $FeCl_3$	0.483	0.480
100 μM $FeCl_3$	0.582	0.363

Is the iron bonding with the Dopa?

Energy Dispersive X-ray Spectroscopy (EDX)

Threads soaked in iron treatments, put through chemical analysis without being stretched:

Iron Treatment	Weight % Fe in sample	
	First spot on thread	Second spot on thread
Buffer	0.183	0.455
1 μM $FeCl_3$	0.106	0.267
10 μM $FeCl_3$	0.483	0.480
100 μM $FeCl_3$	0.582	0.363

The iron may not be bonding with the Dopa in the threads.

Future Experiments

- Repeat EDX weight percent analysis for confirmation
  - Potentially re-evaluate experimental setup for tensile testing
- Visualization of iron localization for different iron treatments
- Nanoindentation hardness tests

Acknowledgements

- Thanks to YerPeng Tan, Herbert Waite, and the Waite research group for all of their help and support

- Thanks to Arica Lubin, Kari Moran, Maria Napoli, Ofelia Aguirre, the EUREKA Program, and the Center for Science and Engineering Partnerships