Exploring the effects of nanoparticle incorporation on the mechanical properties of hydrogels

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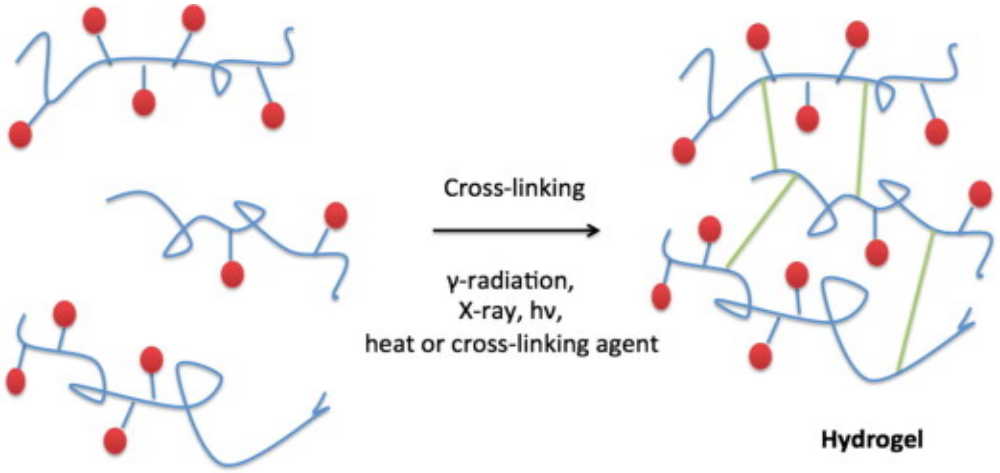
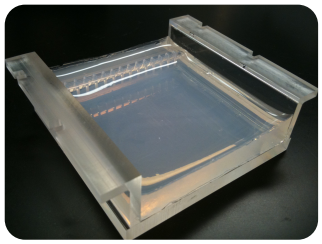
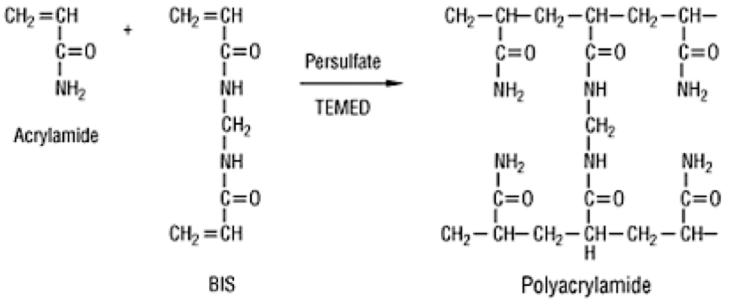
What are hydrogels?



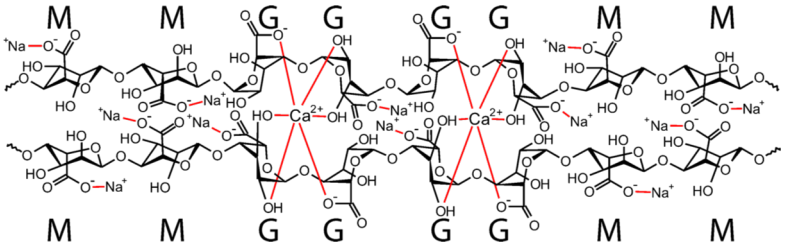
Calo E, European Polymer Journal, 2015



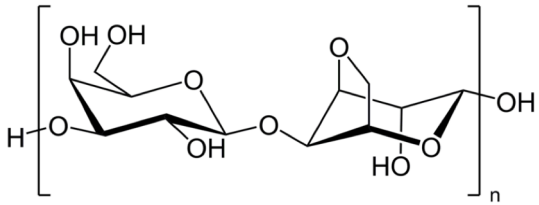
poly(Acrylamide)



Alginate



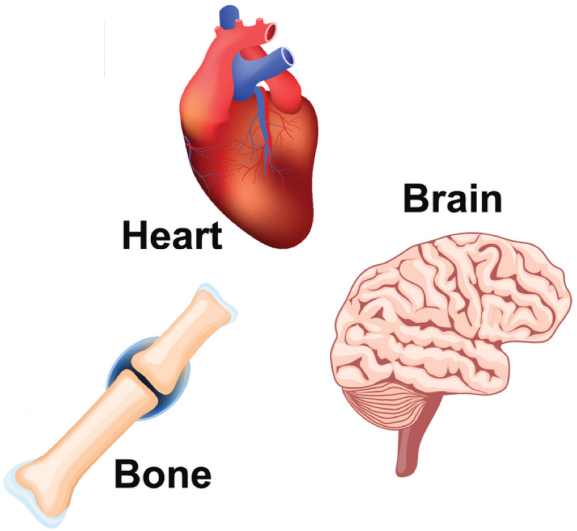
Agarose



Liquid ⇌ Gel (Heating / Cooling)

Need for 'enhanced' hydrogel properties

Tissue Engineering

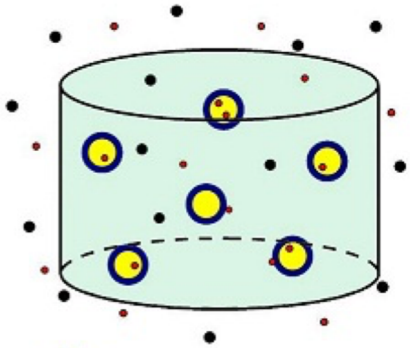


Hydrogel

Wound Healing

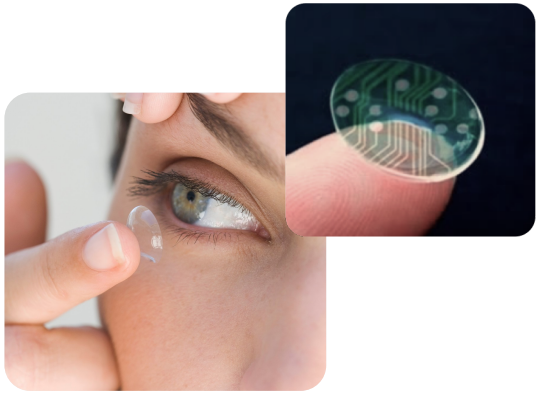
Sahiner N, Current Applied Polymer Science, 2017

Drug Delivery



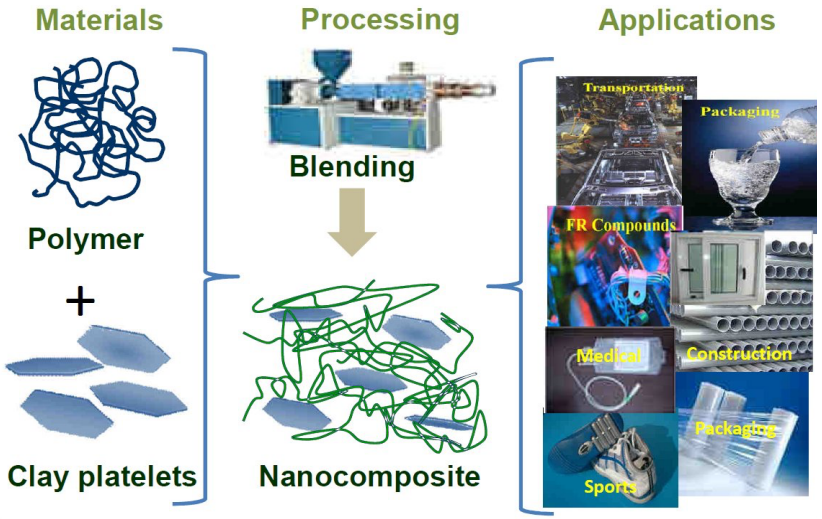
Song PF, Smart Hydrogels, 2014

'smart' Contact Lens

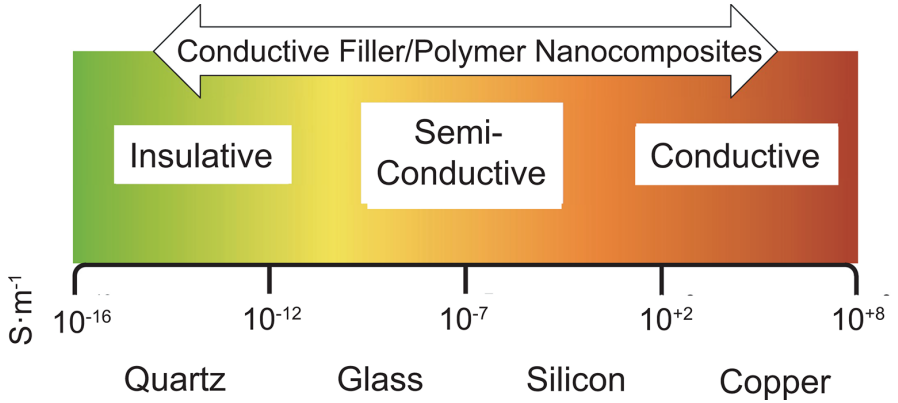


Need for 'enhanced' hydrogel properties

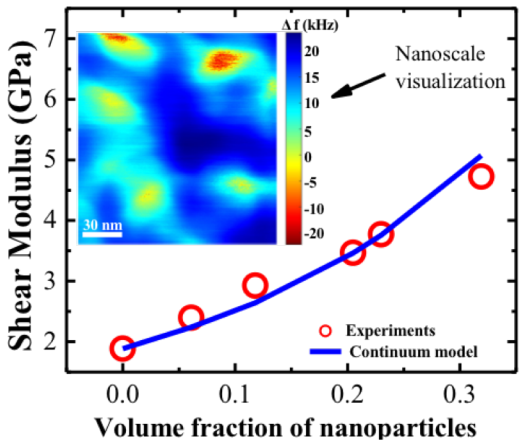
Lessons from polymer nanocomposites



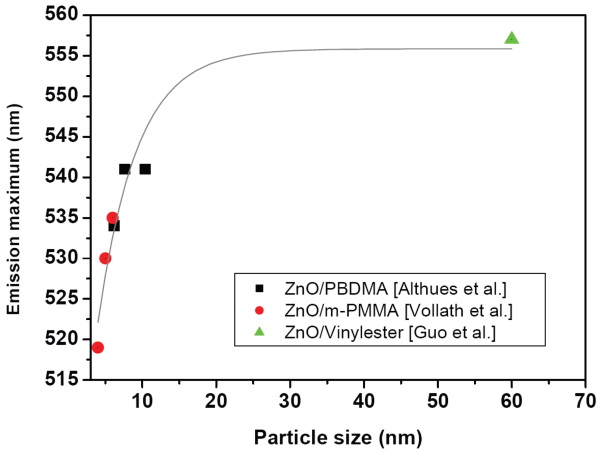
Spiegel S, Advanced Science News, 2014



Arjmand M, in Thermoelectrics for Power Generation, 2016



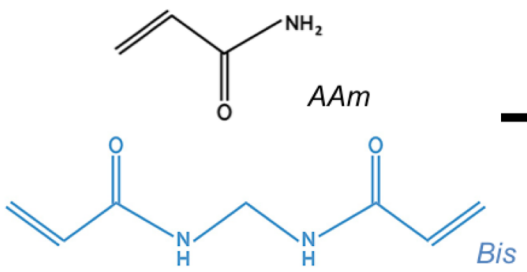
Oak Ridge National Laboratory



Hanemann T, Materials, 2010

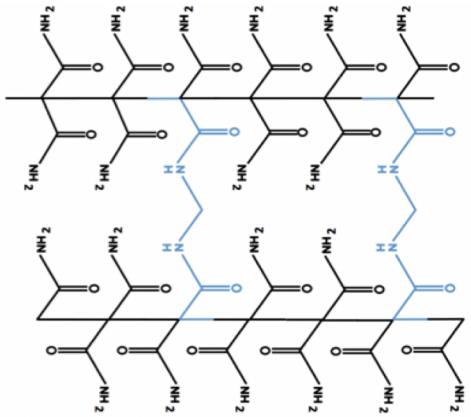
Experimental Setup

Silica nanoparticle reinforced pAAM hydrogels

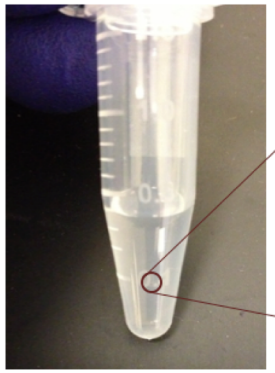


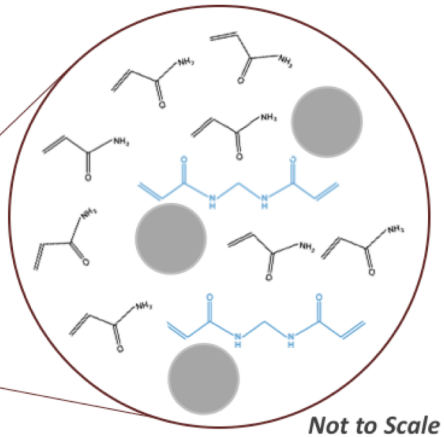
TEMED, APS

25 °C



[AAm], %	[Bis], %	G', Pa
10%	0.25%	1.12×10^4
10%	0.125%	6.58×10^3
10%	0.0625%	4.33×10^3
5%	0.25%	3.30×10^3
5%	0.125%	2.18×10^3
5%	0.625%	8.19×10^2

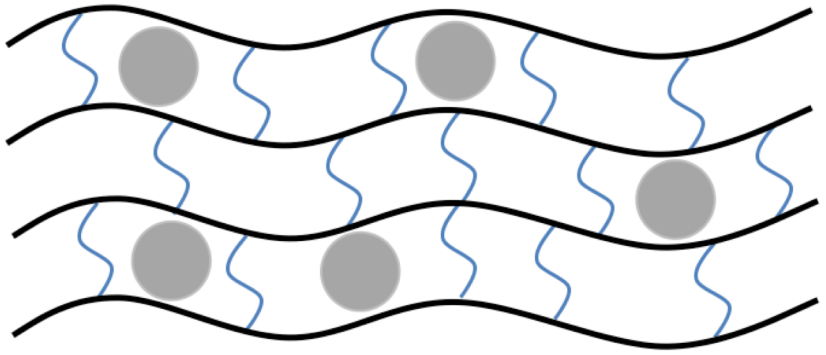




Not to Scale

TEMED, APS

25 °C

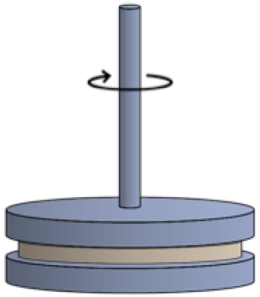


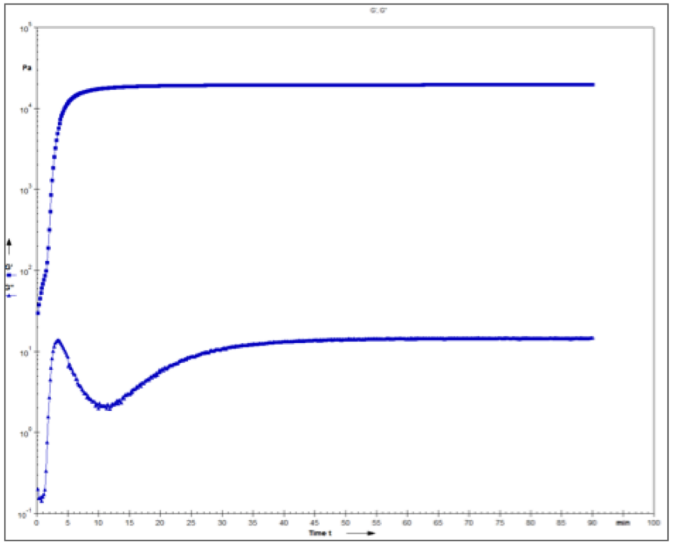
Not to Scale

Experimental Setup

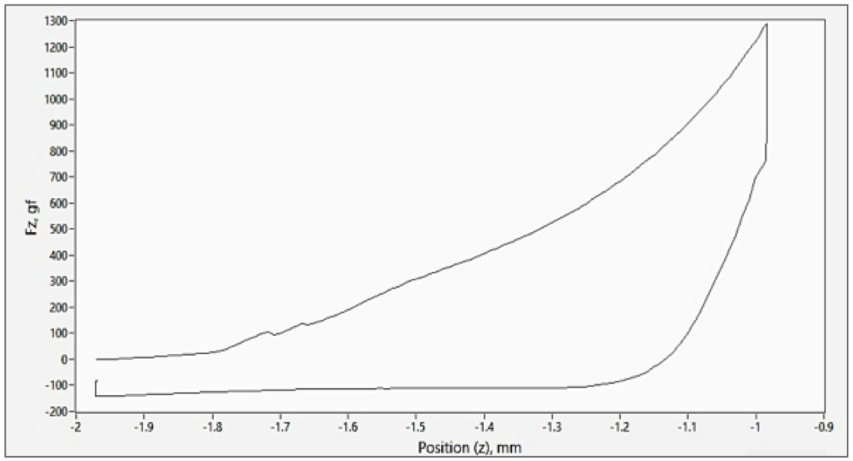
Characterization

Rotational Rheometry – Measurement of shear modulus



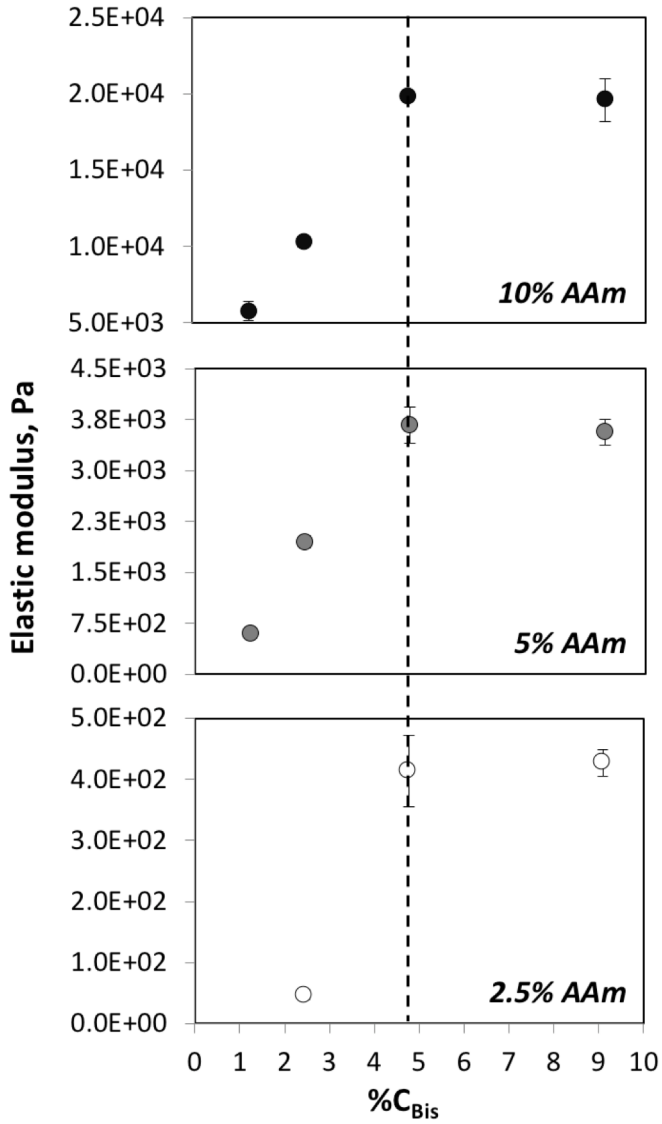


Unconfined Compression – Measurement of compression modulus



Chemical crosslinkers

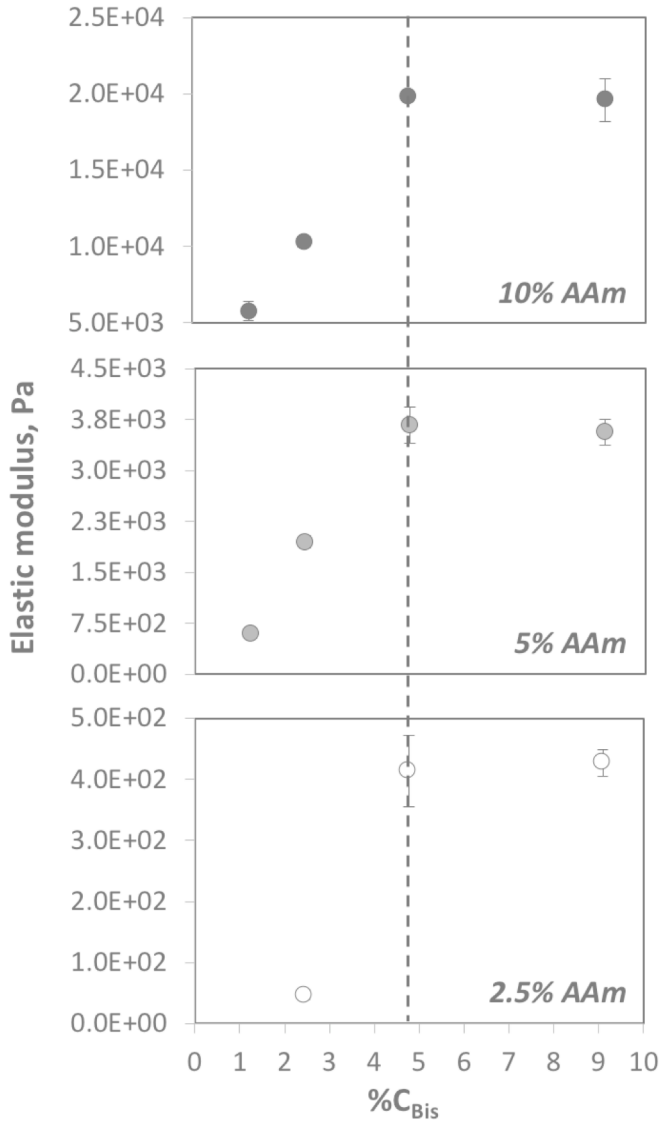
Upper limits in enhancement of mechanical properties

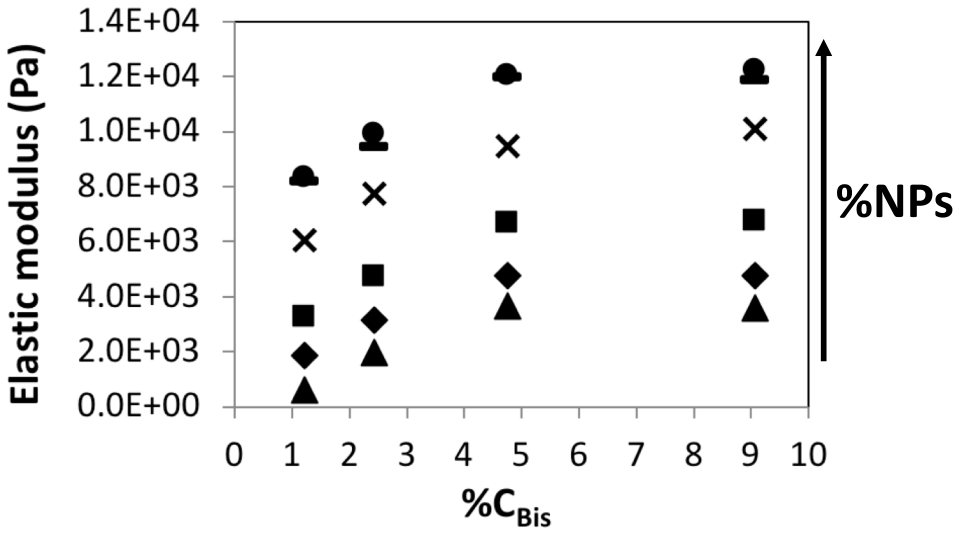


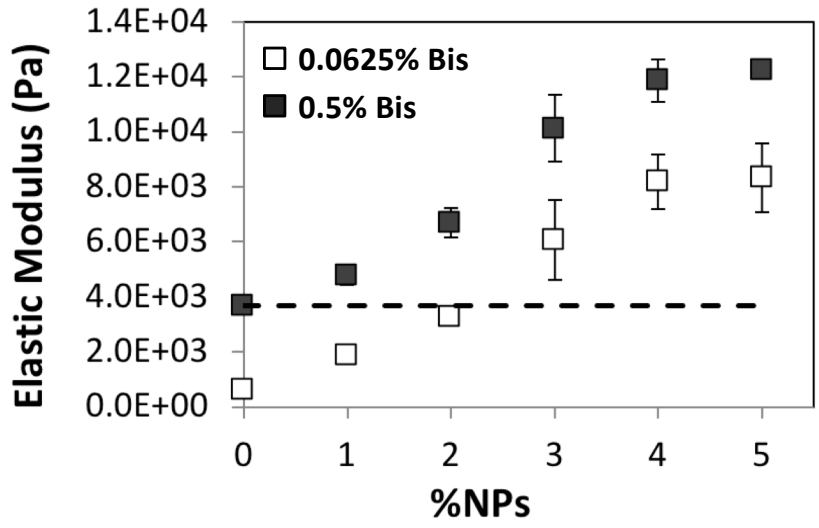
Saturation for G' occurs at the same relative crosslinker concentration (%C_{bis} = 4.76), irrespective of monomer (AAm) concentration

Nanoparticle-mediated enhancements

"Exceeds" chemical crosslinker-mediated enhancements

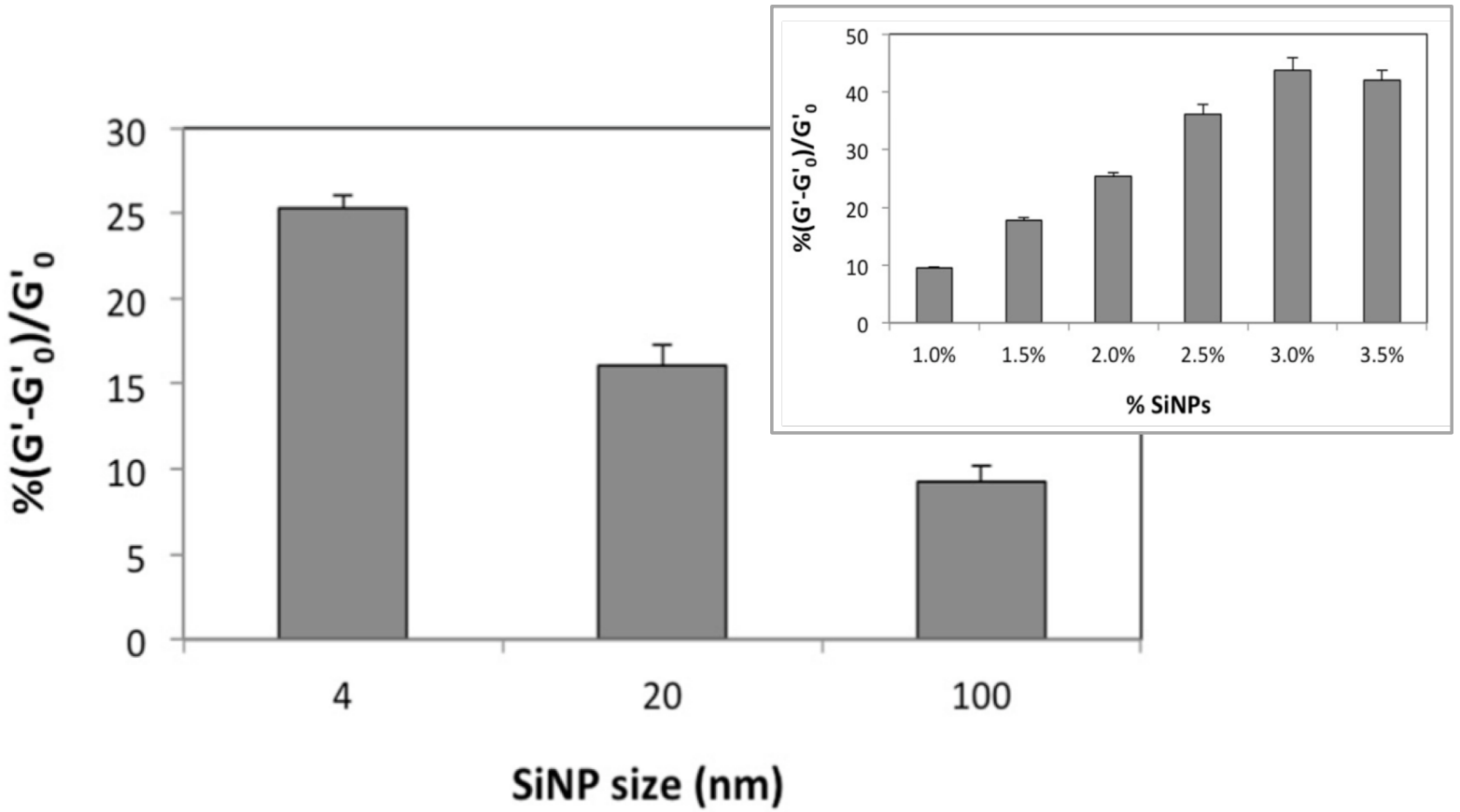






Nanoparticle-mediated enhancements

Role of particle size and concentration

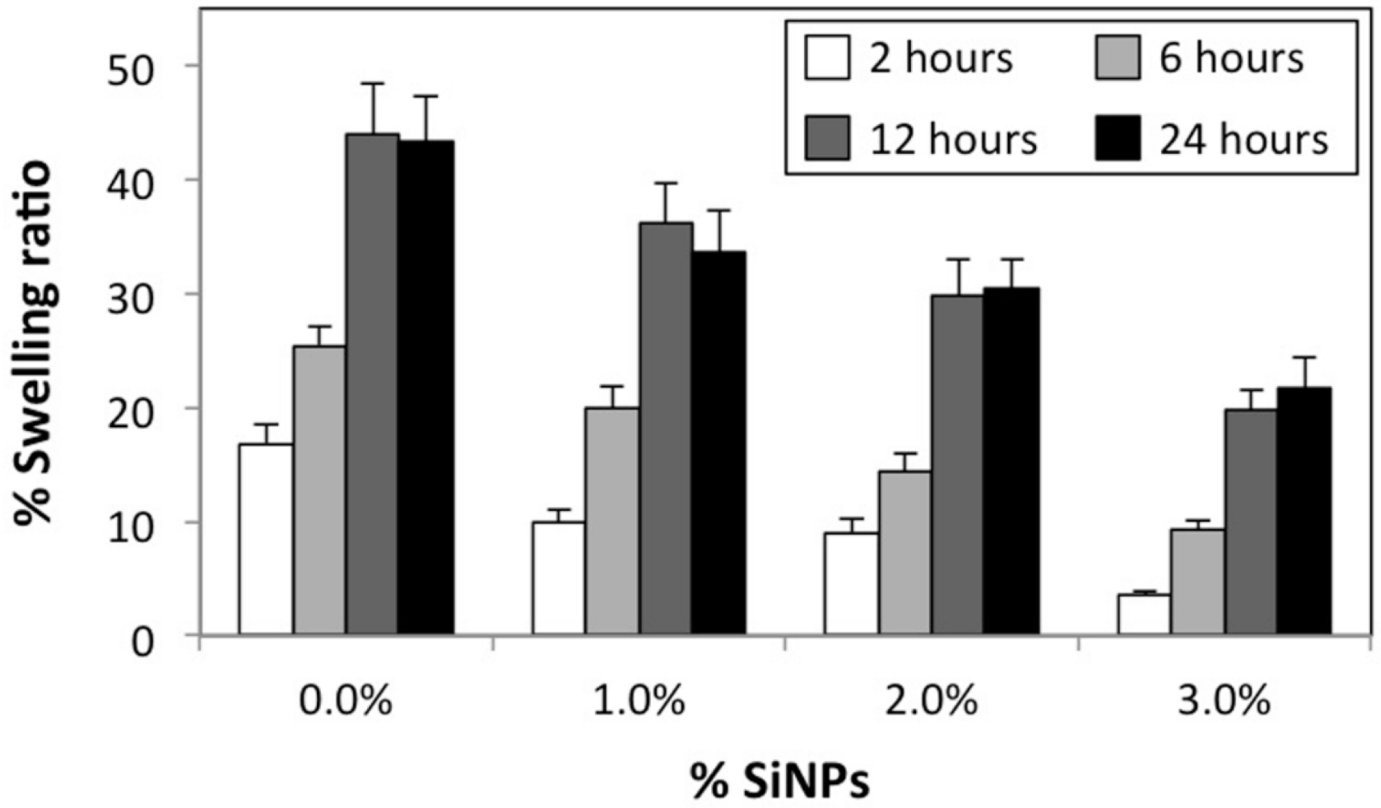


Nanoparticle-mediated enhancements increase with decreasing particle size and increasing particle concentration

Zaragoza J, PLOS One, 2015

Nanoparticle-mediated enhancements

pseudo crosslinking due to particle-polymer interactions

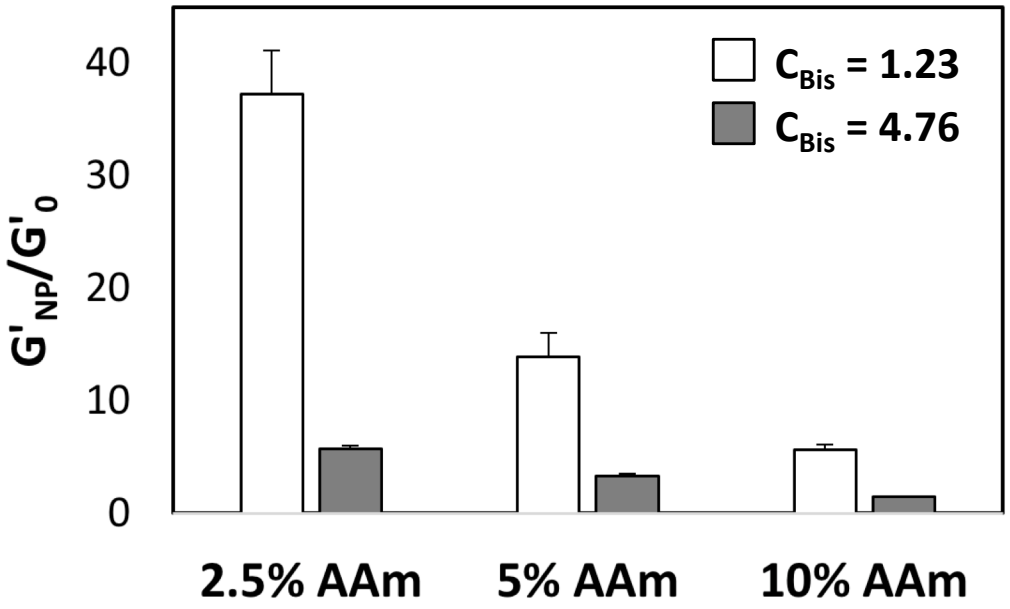


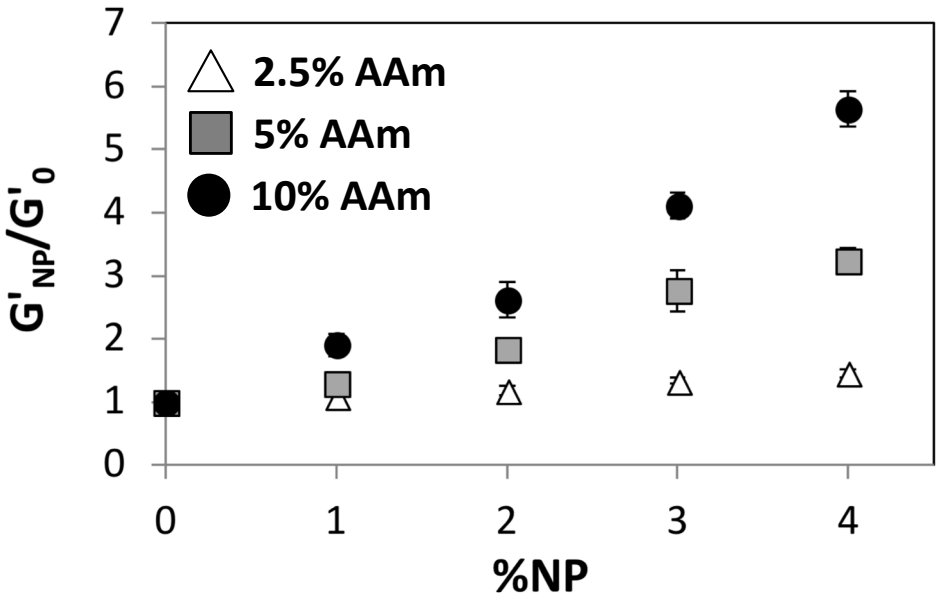
Reduced swelling ratios at higher nanoparticle concentrations, indicating an increase in the average crosslinking ratio

Zaragoza J, PLOS One, 2015

Nanoparticle-mediated enhancements

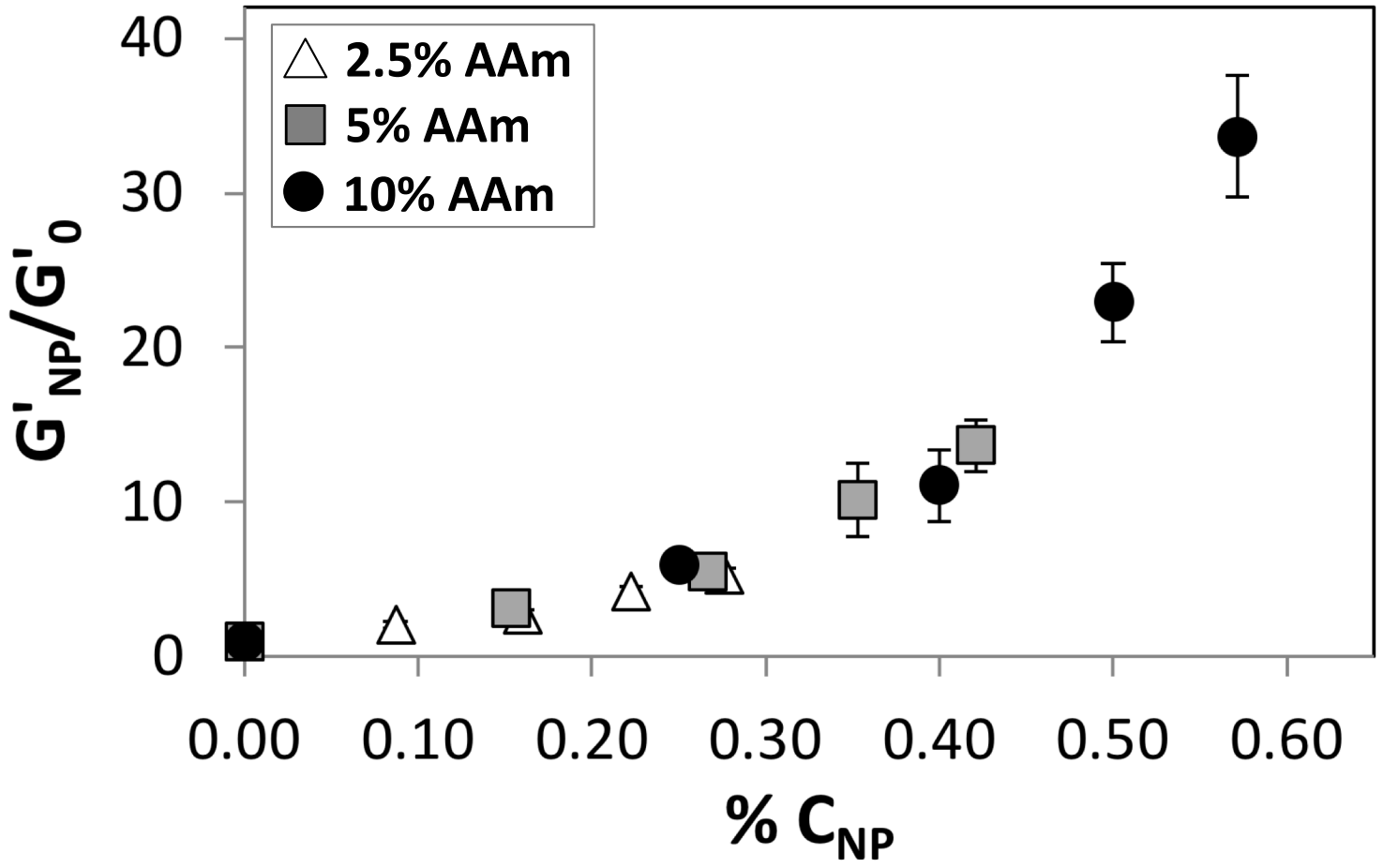
Effects of monomer and crosslinker concentration





Attenuated effects of NPs on the hydrogel elastic modulus at higher crosslinker (Bis) and monomer (AAm) concentrations

Nanoparticle-mediated enhancements



Single master curve for G' for various monomer (AAm) concentrations when plotted against %C_{NP} (normalized nanoparticle concentration) instead of %NPs

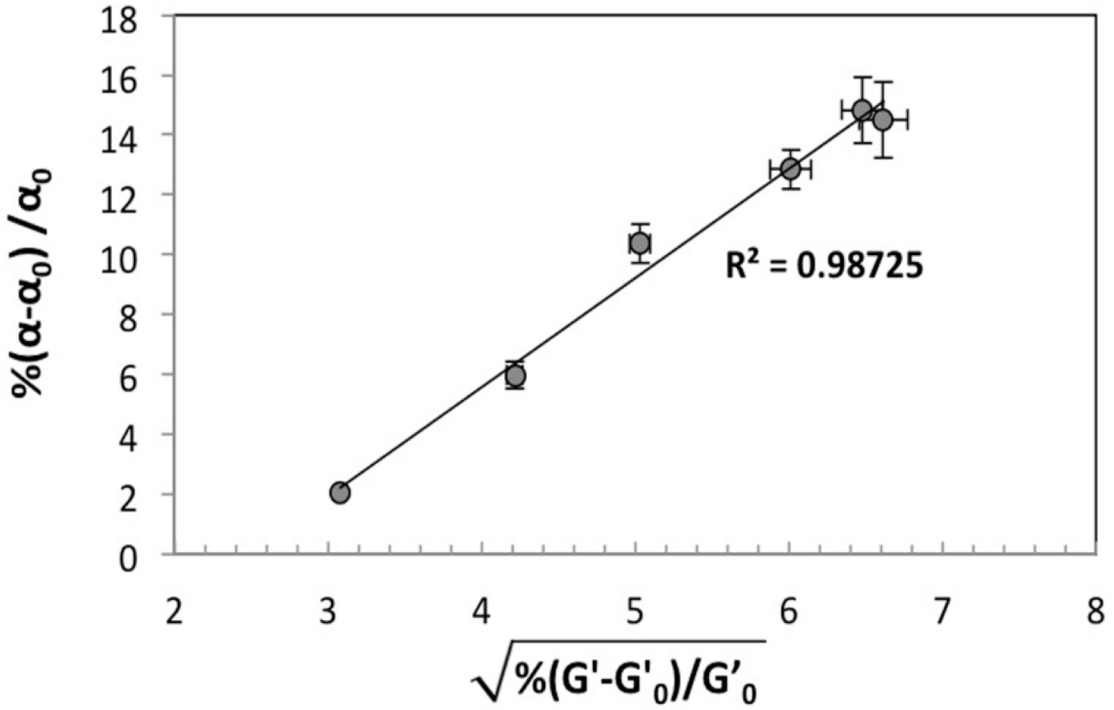
Nanoparticle-mediated enhancements

Enhancements in thermal properties

$$k = \rho C \alpha = \frac{1}{3} C v \Lambda$$

$$v = \sqrt{\frac{E}{\rho}}$$

$$\alpha \propto \sqrt{E}$$



Experimental demonstration of correlatability between enhancements in mechanical and thermal properties of hydrogel nanocomposites

Zaragoza J, PLOS One, 2015

Conclusions & Acknowledgements

Conclusions

- Upper limits to enhancements in hydrogel mechanical properties due to chemical crosslinking alone.
- Nanoparticle-mediated *pseudo* crosslinking exceeds chemical crosslinking mediated mechanical enhancements.
- Enhancements in mechanical properties can lead to improvements in thermal (and perhaps other?) properties of hydrogels.

Acknowledgements

- Dr. James Thomin
- Lee Lab, Santa Clara University

$ School of Engineering, Santa Clara University