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Amy Goshe,
Scientific Information Specialist,
Chemical Abstracts Service

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Upcoming ACS Webinars
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Thursday, September 8, 2016

Systems Thinking To Reimagine Chemistry

Peter Mahaffy, Professor of Chemistry, The King's University and Co-director, The King's Centre for Visualization in Science, Edmonton, Alberta, Canada

Alain Krief, Executive Director of International Organization for Chemical Sciences in Development

Thursday, September 15, 2016

Unveiling the Mysteries Behind HPLC and GC Resolution: From Theory to Practice in 30 minutes

Lee Polite, President and Laboratory Director, Axion Analytical Labs, Inc. and Axion Training Institute, Inc.

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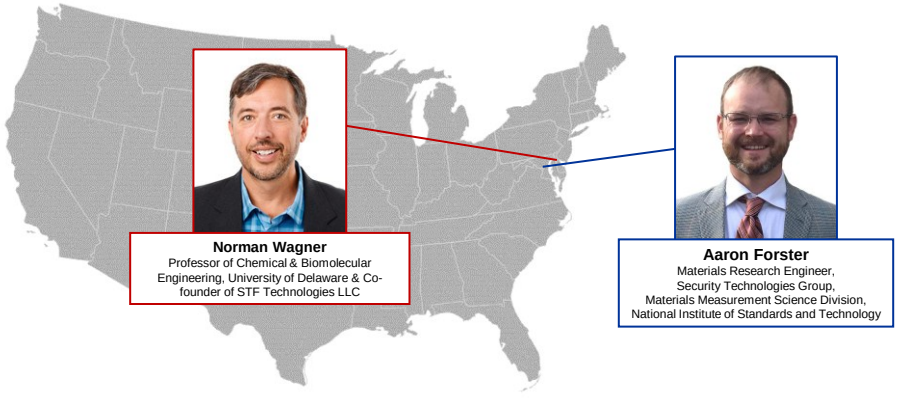
2016 Material Science Series

"Future Protective Materials for First Responders, Football Players, and Astronauts: Shear Thickening Fluids"



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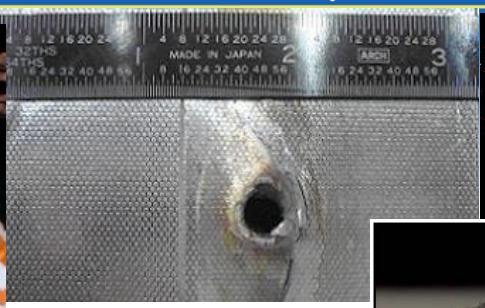
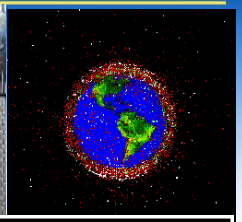
Future Protective Materials for First Responders, Football Players, and Astronauts: Shear Thickening Fluids

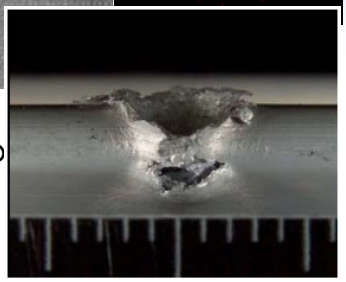
Norman J. Wagner
Co-founder, STF Technologies LLC
Robert L. Pigford Chaired Professor of
Chemical and Biomolecular Engineering,
University of Delaware, Newark, DE 19716 USA
wagnernj@udel.edu

Dreams of Mars…..... What will it take?

Protecting Astronauts and Spacecraft in LEO



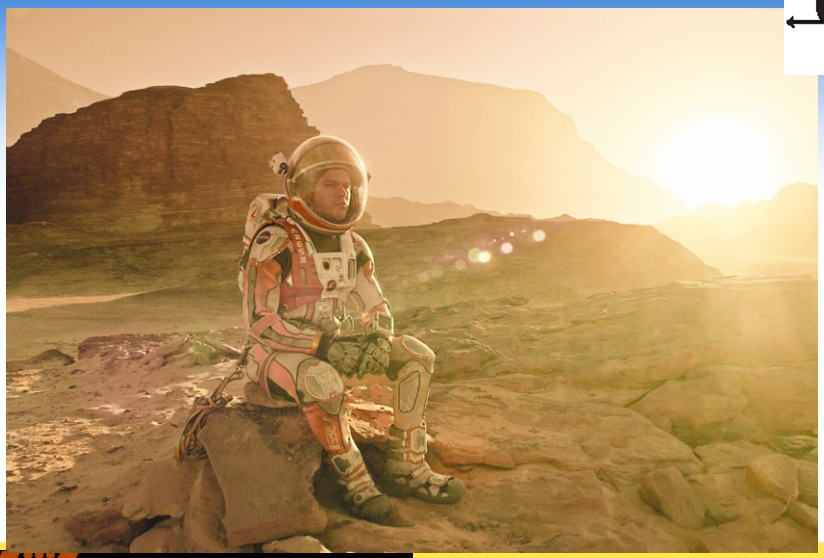


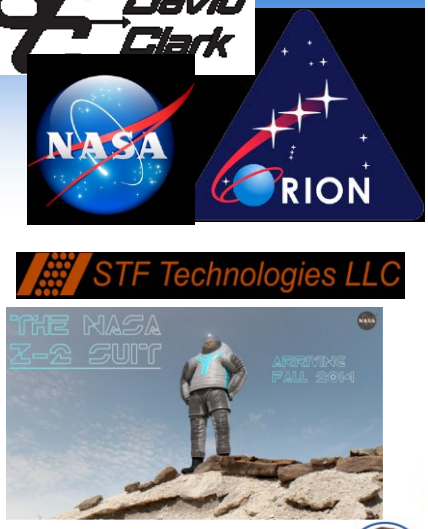


Space Shuttle *Endeavour* suffered significant MMOD impact on radiator, Mission STS-115.

Ryan, S., et al., Mitigation of EMU Cut Glove Hazard from Micrometeoroid and Orbital Debris Impacts on ISS Handrails. 2009

Dreams of Mars: How will we survive?





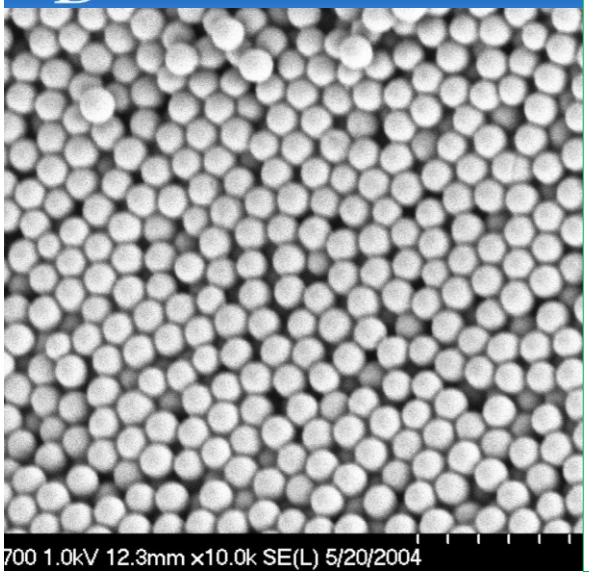
Shear Thickening Fluids: What are they? How do they function?

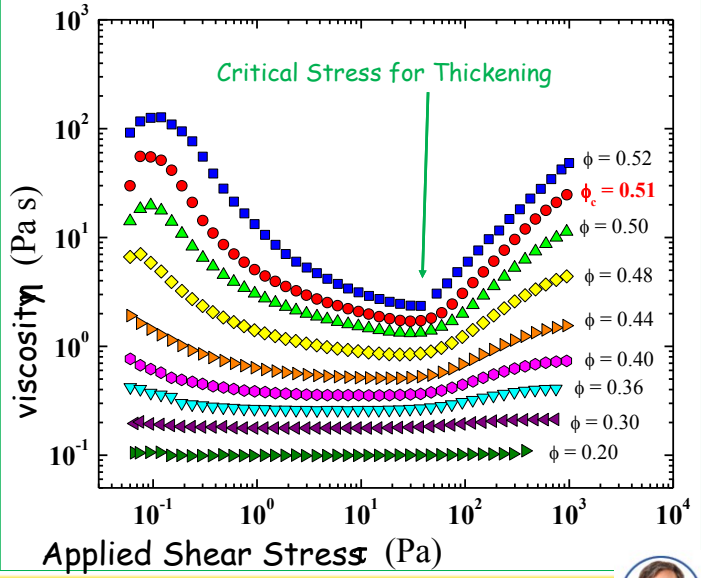
Shear Thickening Fluid: *'Oobleck'*

MythBusters Episode 78:
Walking on Water

By Source (WP:NFCC#4), Fair use, https://en.wikipedia.org/w/index.php?curid=39011157

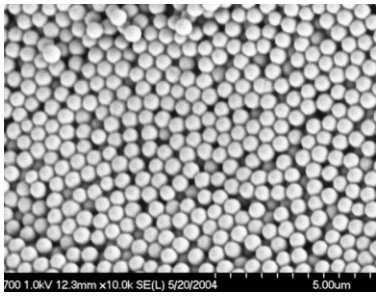
Colloidal Dispersions Shear Thicken

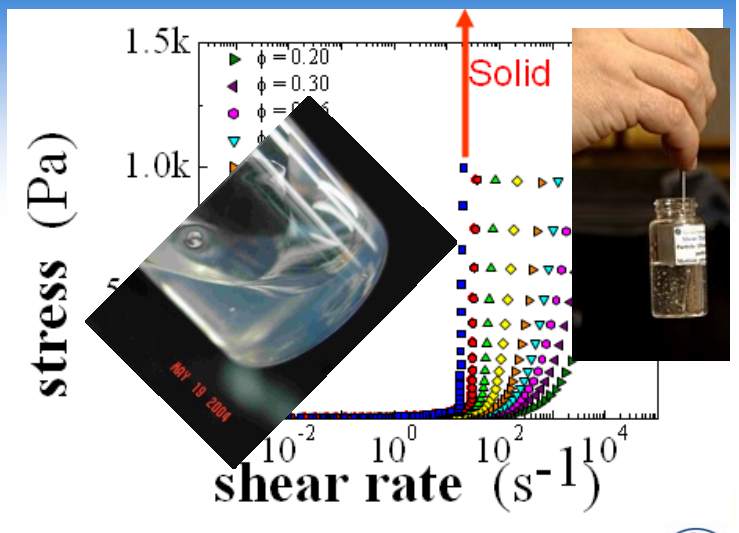




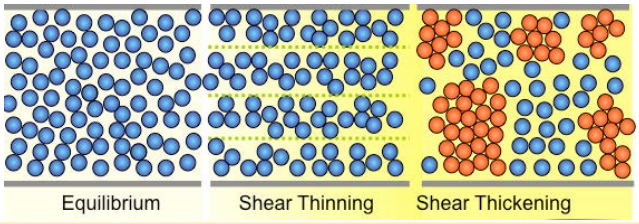
Shear Thickening Physics: Liquid Ceramic

A suspension of ceramic nanoparticles transform from a liquid to a solid upon the application of a critical stress

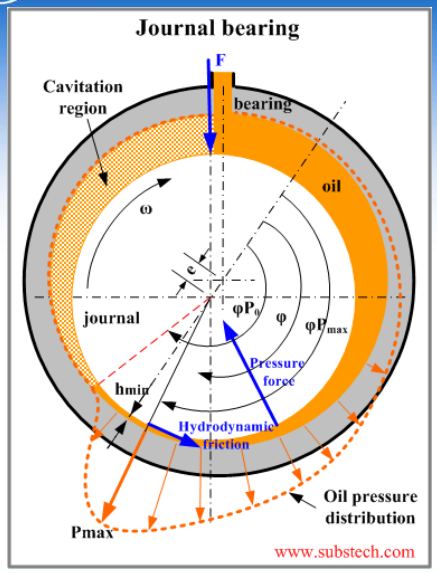




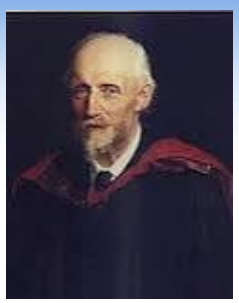
How does shear thickening fluid work?

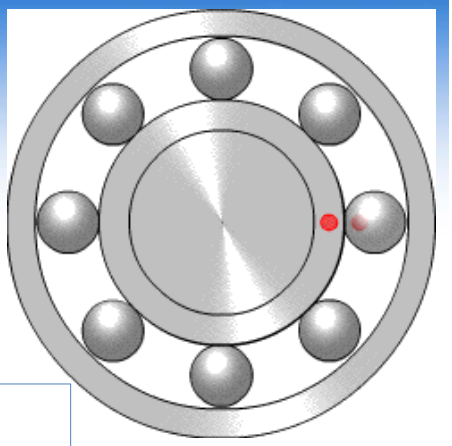


Reynolds (1886) Lubrication Theory for Bearings



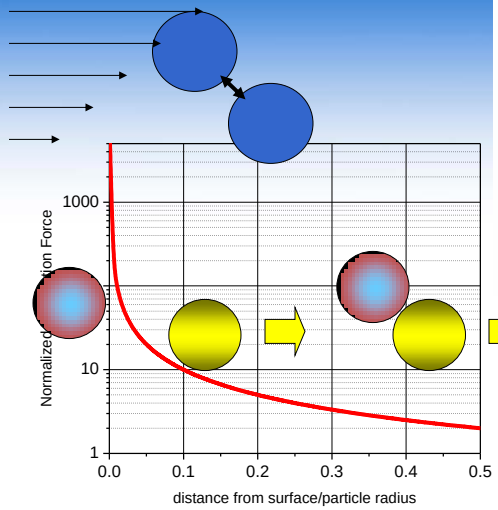
Osborne Reynolds'

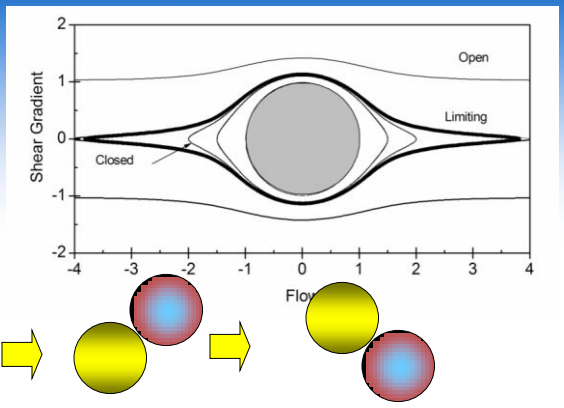




Low Reynolds number
Newtonian Fluid
Thin gap
P increases with decrease in gap

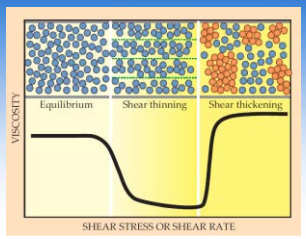
KEY PHYSICS: Lubrication Hydrodynamics

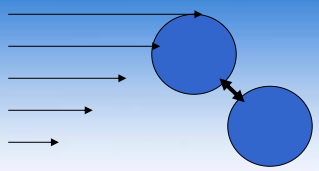




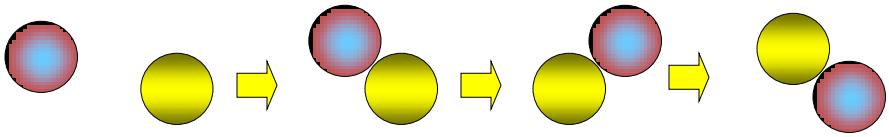
G.K. Batchelor, JFM '72

HOW TO MAKE A GOOD STF?





1. Force of Shear can overcome stabilization forces (i.e., charge, surfactants, polymer….)

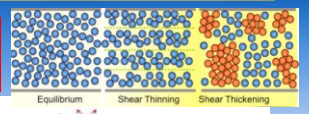


2. Once together, the hydrocluster lifetime must be longer than the shear time scale pulling them apart!

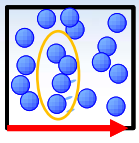
Maranzano & NJW, J. Chem. Phys. 114: 23 (2001), 10514-27

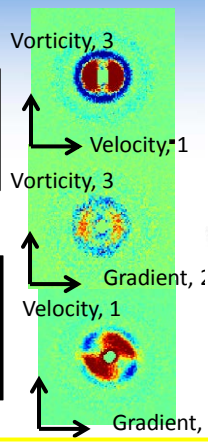
Microstructure in Shear Thickened State

"Microstructure and Rheology Relationships for Shear Thickening Colloidal Dispersions," A. K. Gurnon & N. J. Wagner , *J. Fluid Mechanics*, 2015

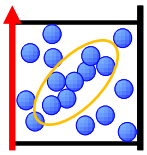


Anisotropy in pattern reflects a propensity for particles to align along the vorticity direction.

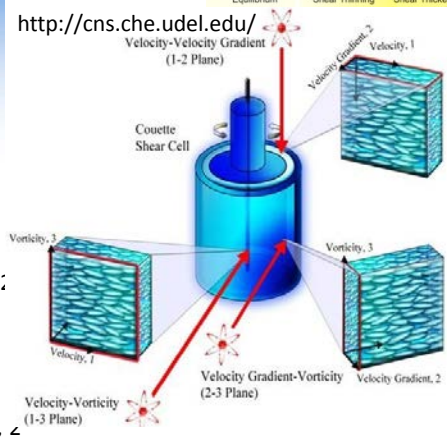




Reflects anisotropy in local microstructure along the compression axis.



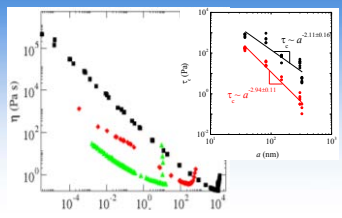
http://cns.che.udel.edu/



Neutron Scattering under flow confirms hydrocluster mechanism of shear thickening.

Colloid Chemistry Control of STF Rheology

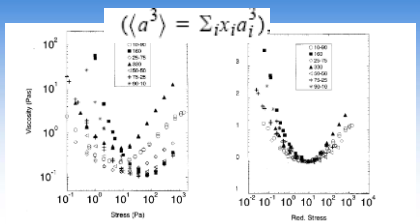
Size



Maranzano & NJW, J Rheo. 2001

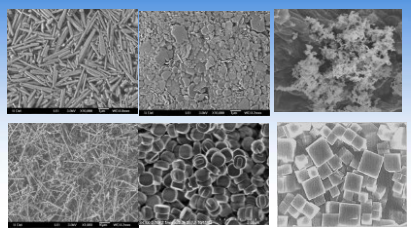
Polydispersity

$(\langle a^3 \rangle = \Sigma_i x_i a_i^3)$

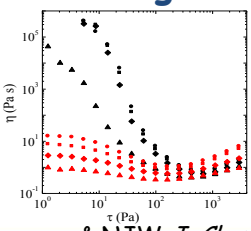


Bender & Wagner, J. Rheology, 1996

Shape

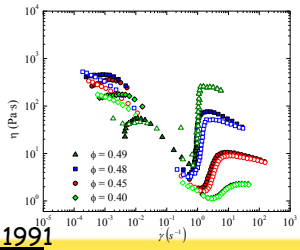


Charge

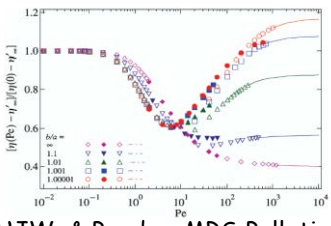


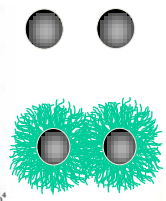
Maranzano & NJW *J. Chem. Phys.* 1991

Particle Hardness



Surface Coating



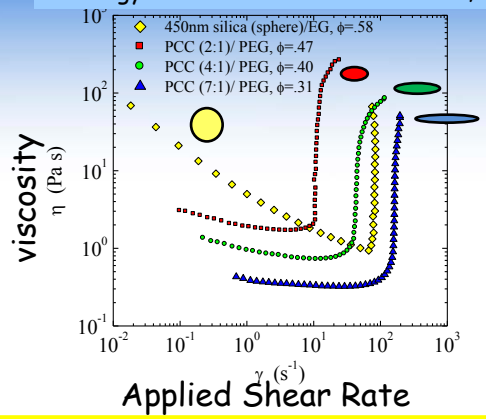


NJW & Bender, MRS Bulletin, 2004

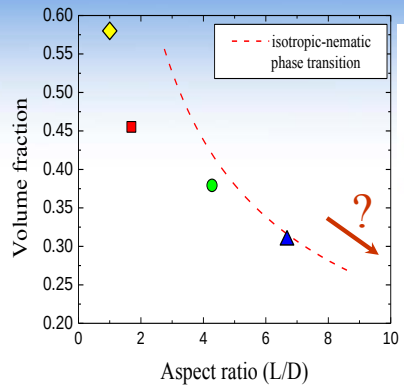
Anisotropic particle STF : aspect ratio

Egres & NJW, J. Rheology 49 p. 715 (2005)

Rheology near critical volume fraction, f_c



Critical volume fraction vs. aspect ratio

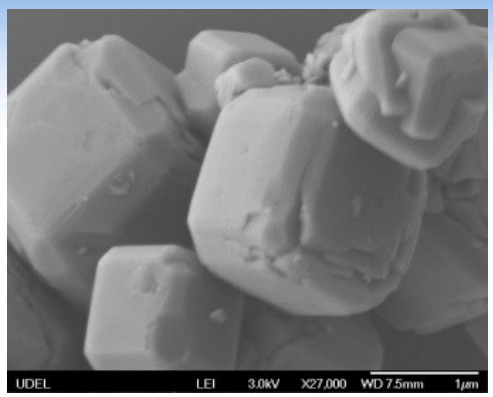


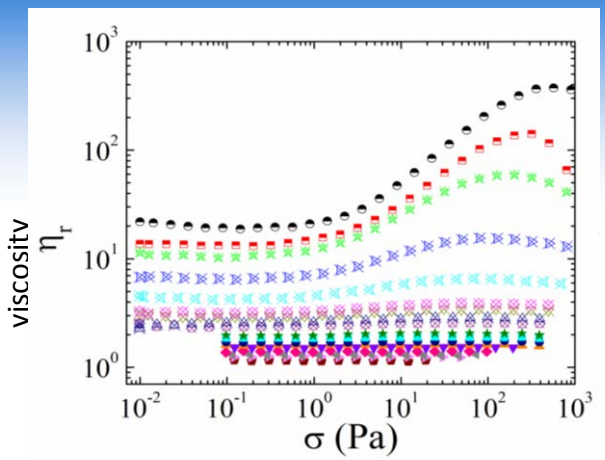
Nick Martys, NIST

- Increasing anisotropy results in discontinuous shear thickening at lower particle loadings
- Viscosity at Φ_c is reduced with increasing particle anisotropy

CUBES- Shear Thickening

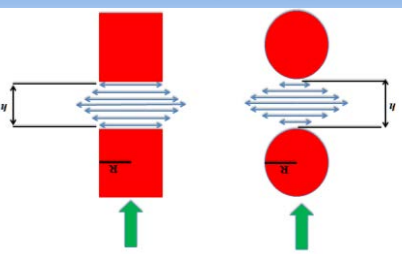
Cwalina et al. Soft Matter, 2016



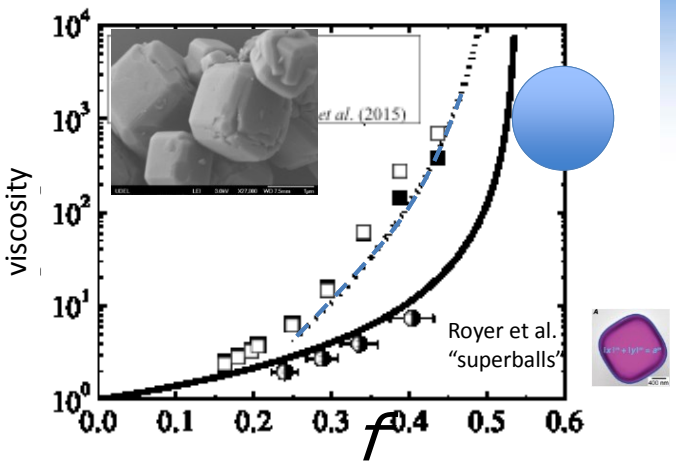


Cubes Show Stronger Shear Thickening

Cubic colloids in suspension show hydrodynamic shear thickening : Cwalina et al. Soft Matter, 2016



Hydrodynamic interactions are much stronger between cubes with flat surfaces than between spheres



Thought Question:

Cement is comprised of colloidal particles and its strength directly depends on the particle density.

How would you change the particles to make super strong cement?

(but remember, you have to pour it!)

Possible Answers:

a) polydisperse size distribution

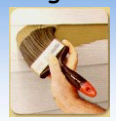
b) adsorb low Mw polymer

c) both a & b

d) None of the above

Preventing Shear Thickening: Engineering Materials to Flow

- Creating new concrete-self compacting and ultra-high performance
- Flowing Paint and Toothpaste
- X-ray film, paper coating, etc..



New Tappan Zee Bridge

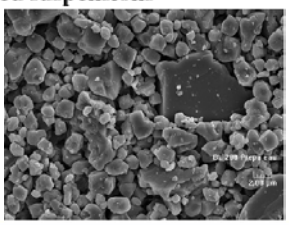
DUPONT The miracles of science

Kodak

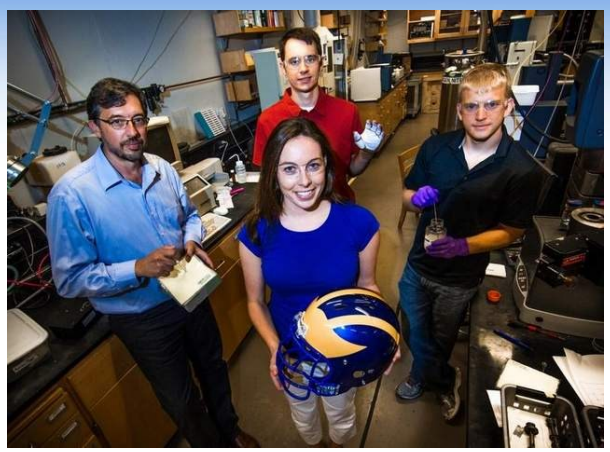
Reducing shear thickening of cement-based suspensions

Fabrice Toussaint · Cédric Roy · Pierre-Henri Jézéquel

LAFARGE CEMENT

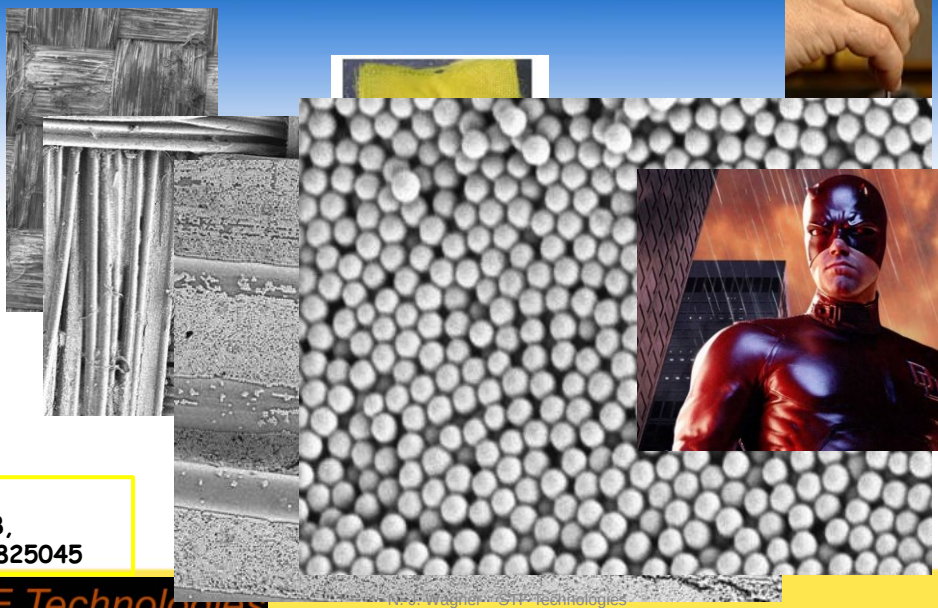


STF-Based Personal Protective Materials



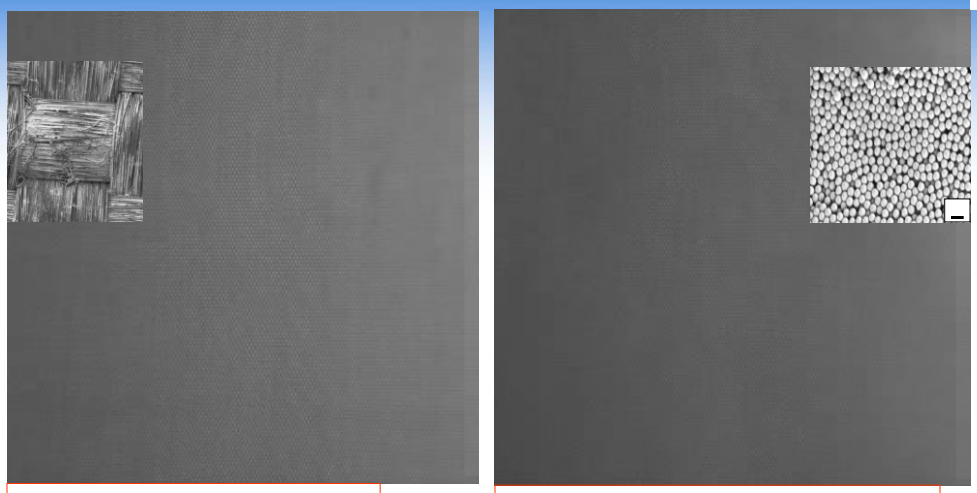
(Image courtesy of the Wilmington News Journal, 2013)

STF-Armor ™



Patents:
US 7226878,
7498276, 7825045

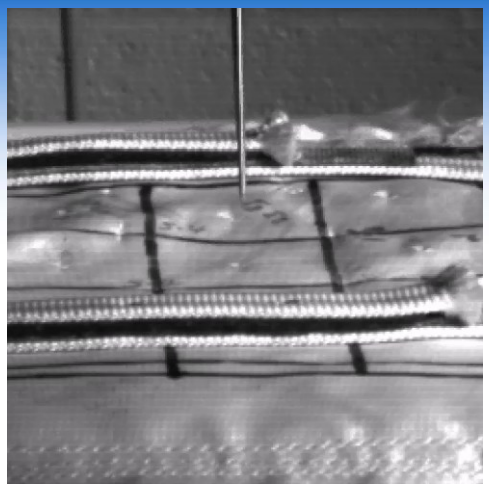
Ballistic Performance



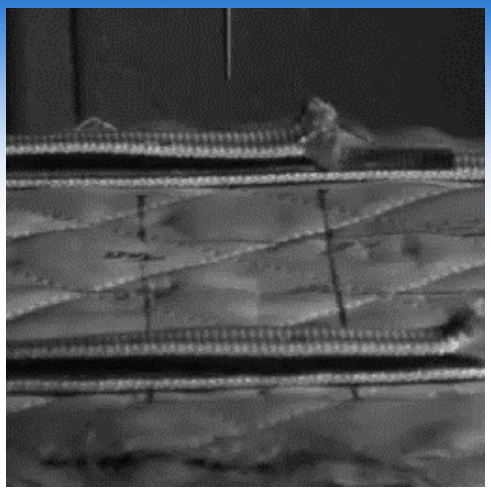
3 layers Kevlar, 1200 fps

3 layers STF-Kevlar, 1200 fps

Stab-Resistant STF Kevlar



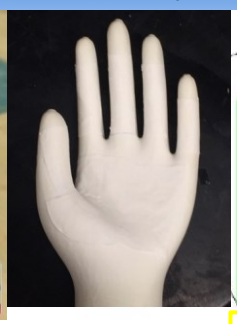
Neat Kevlar- Spike 43 Joule Impact

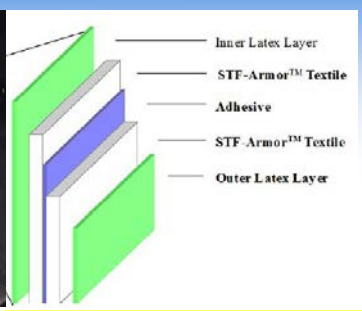


STF Kevlar- Spike 65 Joule Impact

Puncture-Resistant Surgical Glove

350,000 needle-stick injuries per year;





US Patent Application #US2011/031546

The only puncture-resistant glove that offers needlestick protection with the comfort, dexterity and tactile sensitivity that surgeons demand

STF Technologies LLC

National Science Foundation
WHERE DISCOVERIES BEGIN

SBIR/STTR
SMALL BUSINESS INNOVATION RESEARCH
SMALL BUSINESS TECHNOLOGY TRANSFER

Thought Question:

STF-Armor™ can stop needles, spikes, and even bullets- but how fast must it be to stop a micrometeoroid?

data:

- 9mm handgun muzzle velocity: ~400 m/s,
- MMOD ~3 km/s
- Thickness of body armor ~ 2cm
- Thickness of absorber layer ~6mm

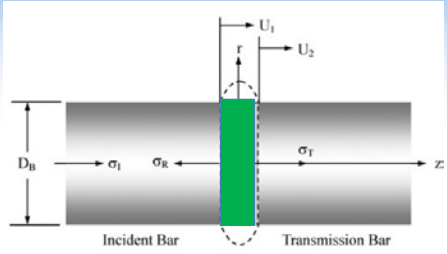
Possible Answers:

a) 1 millisecond b) 50 microseconds c) 2 microseconds d) 1 picosecond

Time Required: Impact Testing

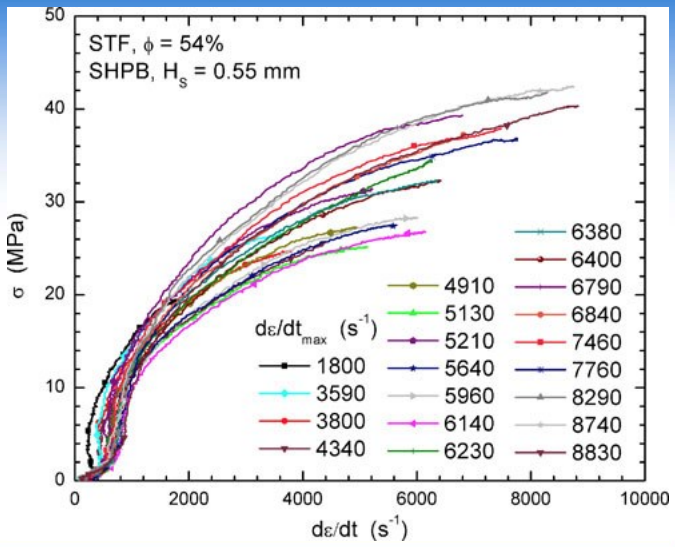
Split-Hopkinson Pressure Bar

Lim *et al. Rheol Acta* ***49*** *(2010) 879-890*



$V \sim 10^3$ m/s ; $t^* \sim 10^{-6}$ s

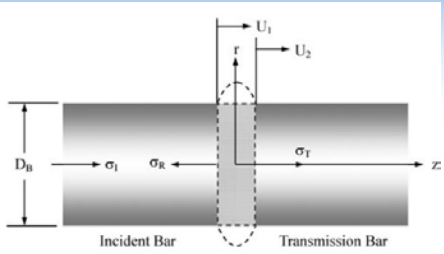
$D \sim 1$ mm

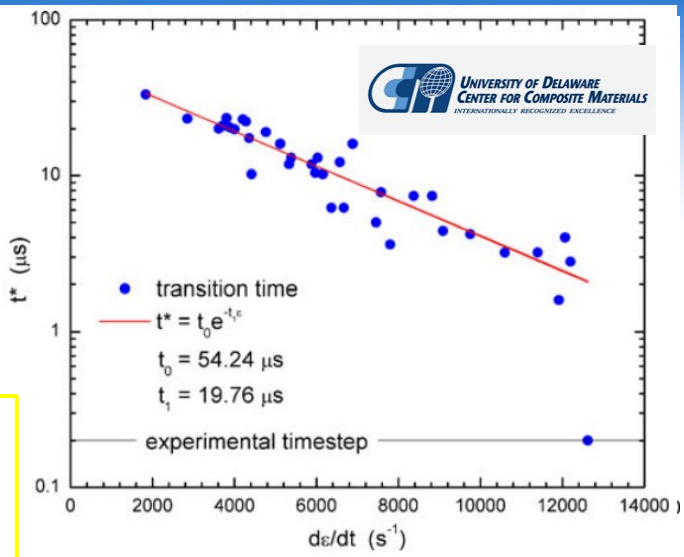


Time Required: ~ Microseconds!

Split-Hopkinson Pressure Bar

Lim *et al. Rheol Acta* ***49*** *(2010) 879-890*



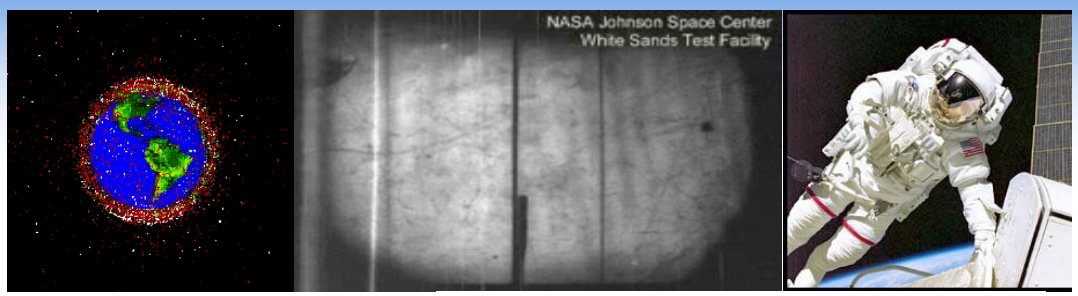


~20 Microsecond response is expected based on propagation of hydrodynamic lubrication forces.

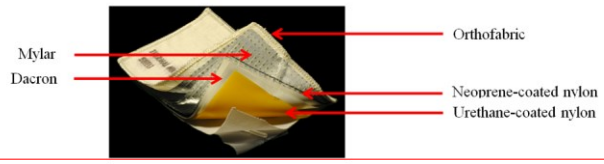
STF Technologies

Hazards of Space Operations

micrometeorites and orbital debris
~10 km/sec



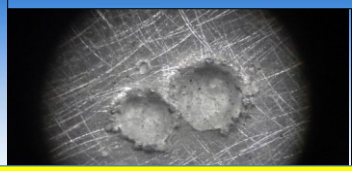
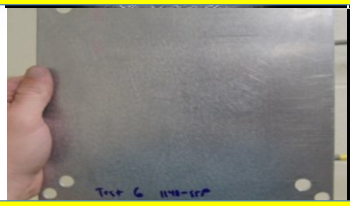
TMG
Thermal Micrometeoroid Garment

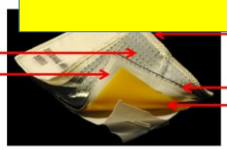


Cwalina, et al., MMOD Puncture Resistance of EVA Suits with Shear Thickening Fluid (STF) – Proc. Eng. 2015

STF Technologies

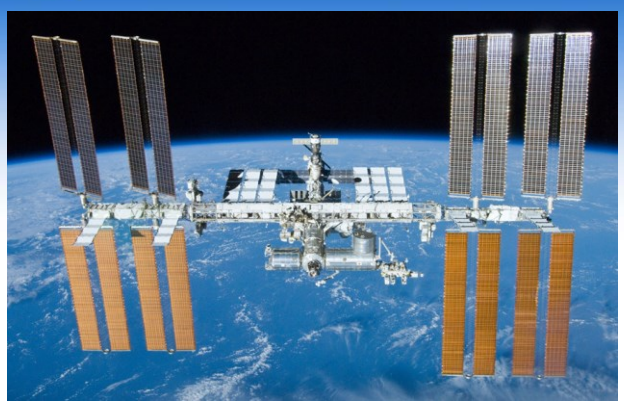
HVI Test Results TMG

	Witness Plate	Backside of Bladder Cloth
Neoprene-coated nylon 3.4 km/s Penetration		
STF-Kevlar 1148 3.3 km/s Intact!		



HVI – Cwalina et al. Procedia Engineering, 2015
Puncture – Cwalina et al. Comp. Sci. Tech., 2016

Next Steps: ISS Flight Experiments



NASA SBIR/STTR
Small Business Innovation Research / Small Business Technology Transfer

David Clark

ORION

Materials International Space Station (ISS) Experiment (MISSE) Flight Facility is a commercially-available materials research facility at the ISS.

Thought Question:

How can we use Shear Thickening Fluids directly in impact and rate-responsive devices for personal protection?

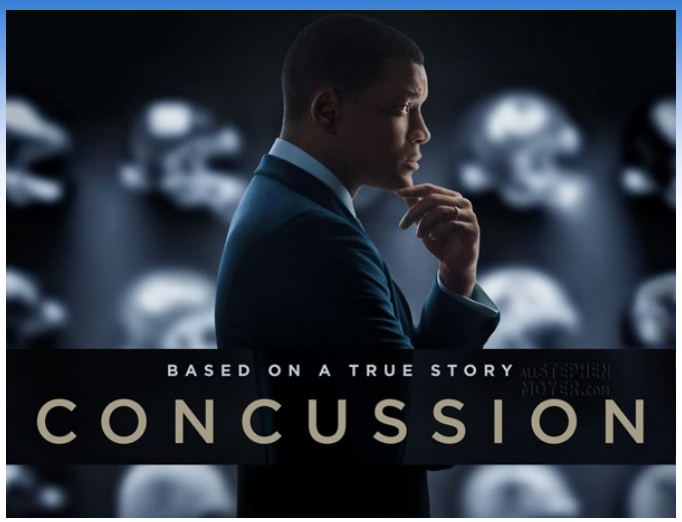
Possible Answers:

a) Wear STF as a rate-responsive lotion
b) Integrate STF directly with foam
c) Use STF as a rate sensitive damper to control linear motion
d) b & c
e) All of the above

STF Applications: Impact Protection

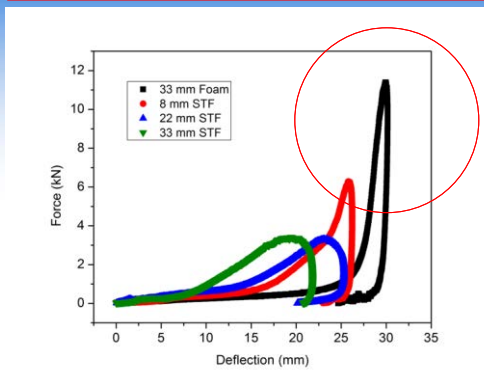
In the U.S. alone,
300,000 sports-related concussions per year

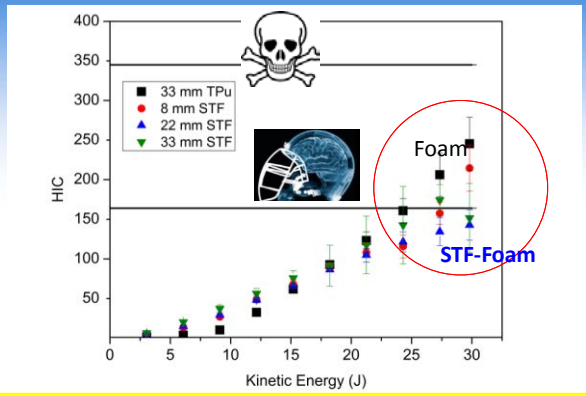
Office of Economic Innovation & Partnerships



Impact Mitigation and Energy Adsorption

(Fowler et al., ASME J. Biomech. Eng. 2015)





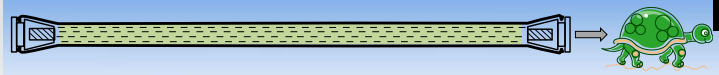
Foam 33 mm
STF (8mm) + 25mm Foam
STF (22mm) + 11mm Foam
STF (33mm)

STF added to performance foam can mitigate the high energy impacts (> 90 g!)

Rate-Activated Tether: "Dynamic Ligament"

HEAD HEALTH CHALLENGE II

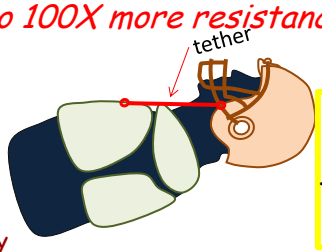
Stretch easily at low speeds…



… but resist stretching at high speeds.

Up to 100X more resistance at high speeds.

Dr. Eric D. Wetzel
U.S. Army Research Laboratory
Aberdeen Proving Ground, MD



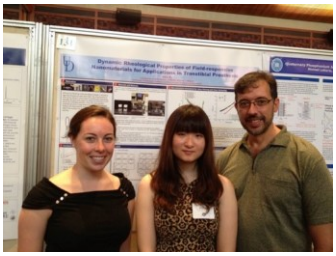
Tethers resist sudden rearward head motions to reduce violent head-to-ground collisions.

Undergraduate Research by Keyi Xu

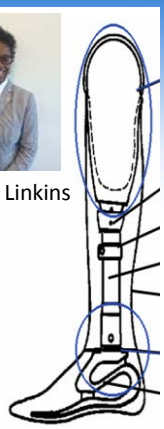
BIOMECHANICS AND MOVEMENT SCIENCE PROGRAM

"Dynamic Rheological Properties of Field-Responsive Nanomaterials for Applications in Transtibial Prosthesis" UD 2015 Senior Thesis

US Patent Filed 2016



Jehnae Linkins

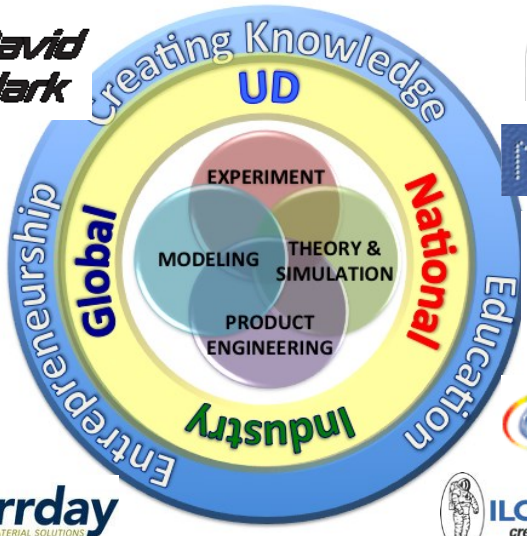


Rate responsive damper

Tether as Achilles tendon

Rate responsive ankle

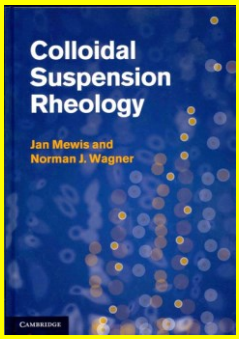
Thank you for your attention! Questions?



Resources for additional learning:

www.stf-technologies.com

www.che.udel.edu/wagner



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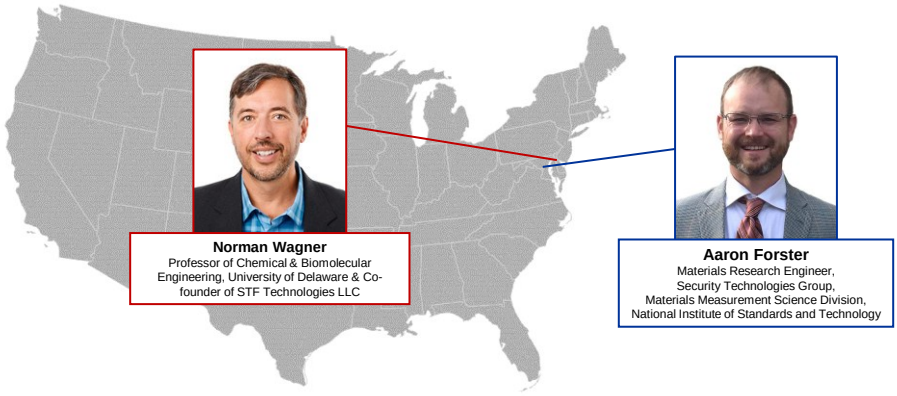

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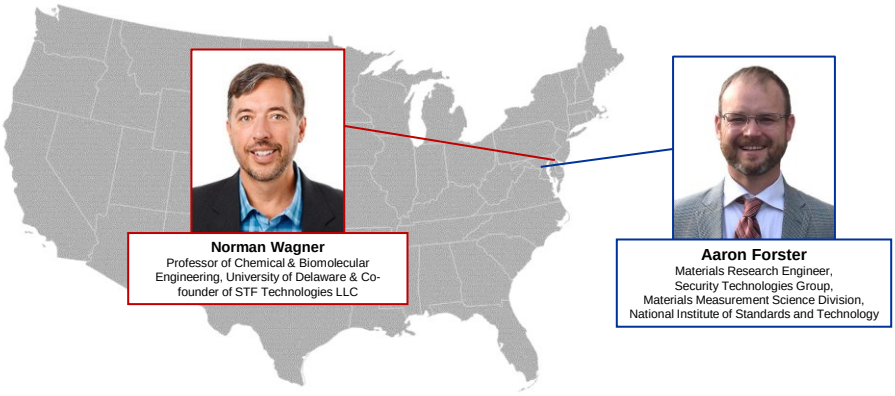

Norman Wagner
Professor of Chemical & Biomolecular Engineering, University of Delaware & Co-founder of STF Technologies LLC

Aaron Forster
Materials Research Engineer, Security Technologies Group, Materials Measurement Science Division, National Institute of Standards and Technology

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