Rheo-physics of Shear Thickening Fluids for applications in ballistic impact protection technology

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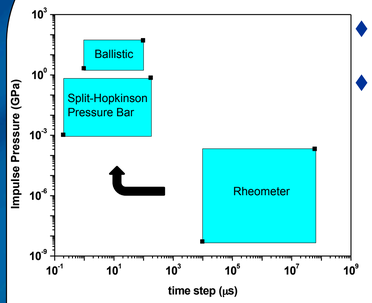
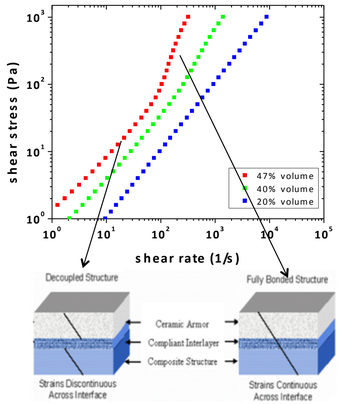
INTRODUCTION



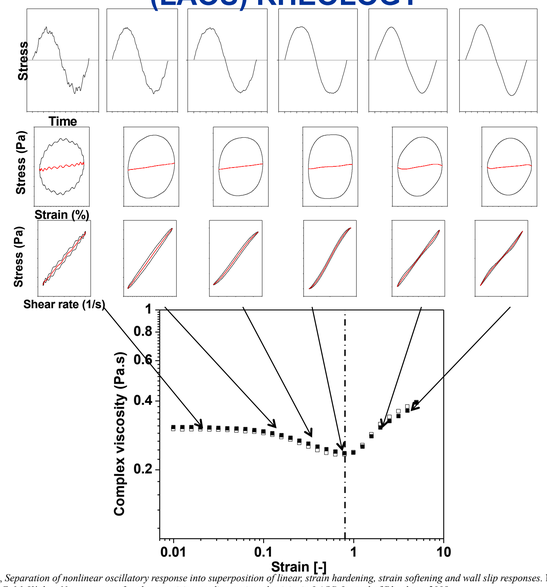
- Previous work has investigated STFs using rheology and SHPB techniques
- Extension to ballistic events requires a means for predicting the STF response at high impulse pressures and small time steps



- Goals toward incorporating STF in an armored vehicle interlayer
  - Understand a STF's response during a transient deformation
  - Effectively predict the response of a STF during a ballistic impact

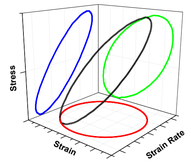
A. Lim, *et al. Investigating the transient response of a shear thickening fluid using the split-Hopkinson pressure bar technique. Rheol Acta 2010*
D.P. Kalman and N.J Wagner,

LARGE AMPLITUDE OSCILLATORY SHEAR (LAOS) RHEOLOGY

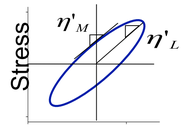


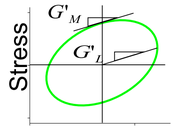
C.O. Klein et. al. , *Separation of nonlinear oscillatory response into superposition of linear, strain hardening, strain softening and wall slip responses.* Macromolecules, 2007
R. H. Ewoldt and G. McKinley, *New measures for characterizing nonlinear viscoelasticity in LAOS,* Journal of Rheology, 2008

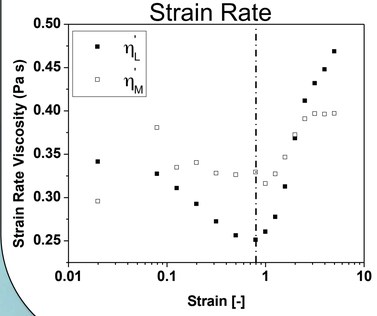
LAOS RESULTS

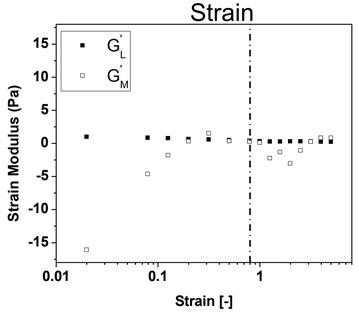


- LAOS rheology allows us to probe the stress, strain and strain rate relationship

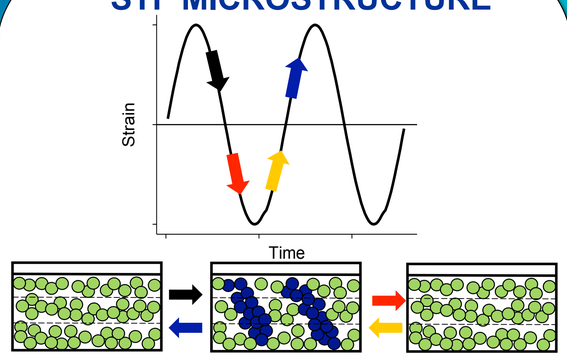






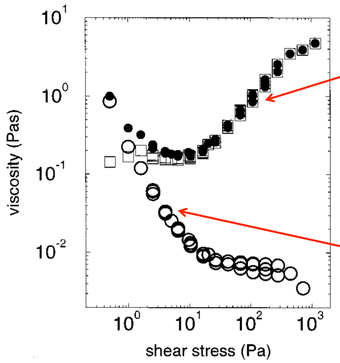


STF MICROSTRUCTURE



Our current understanding for the microstructure of a material during deformation provides the tools to propose a constitutive model that describes the macroscopic stress response based on the underlying microstructural rearrangements.

CONSTITUTIVE MODEL DEVELOPMENT



Hydrodynamic component associated with forces acting between particles due to motion through the suspending fluid.

Thermodynamic component associated with the Brownian motion of the particles

Bender and Wagner. JoR, 1996.

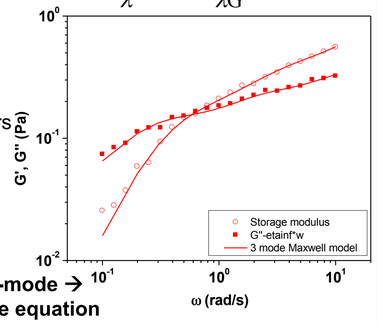
CONSTITUTIVE MODEL: SHEAR THINNING REGIME

Giesekus constitutive equation:

$$\boldsymbol{\tau} = \boldsymbol{\tau}_p + \eta_\infty \mathbf{D}$$

$$\frac{1}{\lambda}\boldsymbol{\tau}_P + \overset{\nabla}{\boldsymbol{\tau}}_P + \frac{\alpha}{\lambda G}\boldsymbol{\tau}_P \cdot \boldsymbol{\tau}_P = 2G\mathbf{D}$$

Where α is the anisotropy parameter originally defined as a flow alignment parameter for polymers systems.

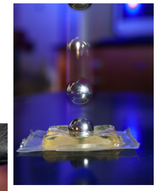


Motivates for a multi-mode → Giesekus constitutive equation

A.K. Gurnon and N. J. Wagner, *LAOS measurements to obtain constitutive model parameters: Giesekus model of banding and nonbanding wormlike micelles.* (Submitted to JoR 2011)

CONCLUSIONS AND FUTURE RESEARCH

- Complete constitutive model development
- Predict responses of STF in SHPB
- Implement STF into technology designed to protect against transient impacts



Pictures and STF incorporated composite materials courtesy of Dr. Rich Dombrowski and Dr. Jeremy Fowler.

ACKNOWLEDGEMENTS

This work is supported by the Army Research Laboratory through the Composite Materials Research program. The authors would also like to thank Dr. Eric Wetzel (ARL).