DYNAMIC RHEOLOGY OF SHEAR THICKENING FLUIDS

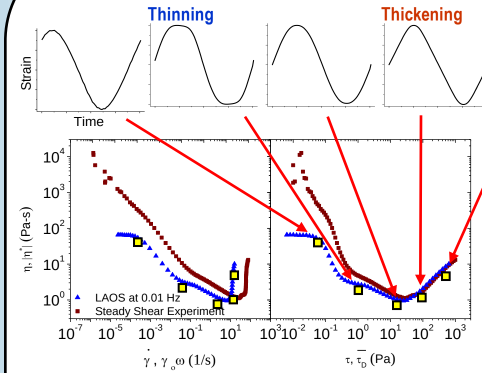
D. Kessler(PhDChE), N. J. Wagner, J. W. Gillespie

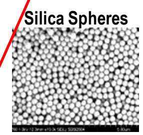
University of Delaware . Center for Composite Materials . Department of Chemical Engineering

Abstract

Shear thickening fluids (STF) are responsive materials with liquid like properties at low stresses and solid like properties at high stresses. This change in behavior has been shown to increase the stiffening and dampening of small scale beam sandwich structures.[1] To develop models and predictions for STF-based devices the dynamic rheology of STF must be understood. Standard procedures for dynamic or oscillatory rheology can not be used due to the high non-linearity of STF. We therefore use a method known as Large Amplitude Oscillatory Shear (LAOS) to obtain the non-linear dynamic rheological data. With LAOS we use a new technique known as Fourier decomposition and superposition to quantitatively analyze the non-linear data.

LAOS Non-Linear Response

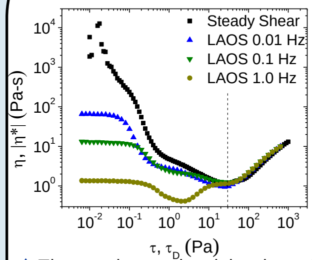


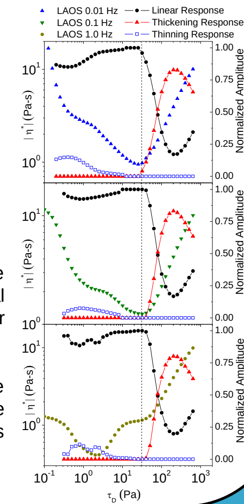


51vol% of 450nm silica spheres suspended in PPG 200.

In a single LAOS experiment of a STF there are non-linear responses from the shear thinning and shear thickening regime. The shear thinning waveforms show a broadening of the wave resembling a rectangle wave where the shear thickening waveforms have sharper points resembling triangles.

Fourier Decomposition and Superposition

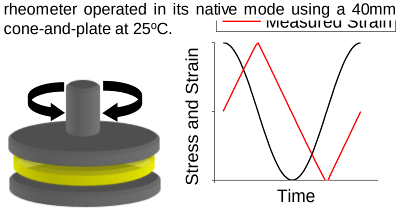




- The graphs on the right show the amplitudes of the rheological responses obtained using Fourier decomposition method.
- At the onset of shear thickening the thickening response dominates the LAOS signal raising three orders of magnitude.

Large Amplitude Oscillatory Shear

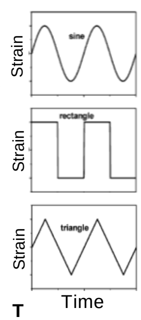
The LAOS technique allows the stress (or strain) and frequency to be varied independently. By going to larger stress and strain amplitudes we are able to probe the dynamic non-linear behavior of STF. Stress is applied to the STF as a sinusoidal wave-form at a fixed frequency and the strain wave-form response is measured. All rheological data were obtained from a stress controlled rheometer operated in its native mode using a 40mm 1° cone-and-plate at 25°C.

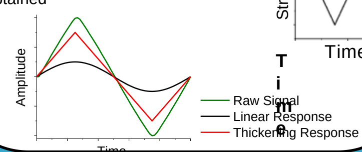


Fourier Decomposition and Superposition

Due to the high non-linearity of the LAOS technique and STF a new type of analysis is required. The non-linear waveforms are recreated using the trial functions on the right. These trial functions represent extreme rheological responses.[2] Following are the steps in the Fourier decomposition method:

- Raw signal converted to Fourier space
- Signal is reconstructed using Fourier transforms of trial functions
- Amplitudes of trial function responses obtained





Conclusions

- The application of LAOS technique was used to obtain dynamic rheological data of STF systems.
- LAOS data is interpreted using new technique that allows quantitative analysis of non-linear rheological response.
- Along with stress as a function of strain amplitude and frequency we now have additional information obtained from the LAOS analysis including the thinning, thickening and linear response as a function of stress

$$\tau = f(\gamma_o, \omega)$$

Future Work

The next step is to complete small scale experiments that use STF as an interlayer in beam sandwich composites. The information obtained through the LAOS and Fourier techniques will be used to model the STF interlayer response.

References

Fischer, C. et. al. Dynamic properties of sandwich structures with integrated shear-thickening fluids. *Smart Mater. Struct.* **2006**, 15, 1467–1475

Klein, C. O. et al. Separation of the Nonlinear Oscillatory Response into a Superposition of Linear, Strain Hardening, Strain Softening, and Wall Slip Response. *Macromolecules* **2007**, 40, 4250-4259

Acknowledgements

This work is supported by the Army Research Laboratory through the Composite Materials Research program.

Wagner Research Group
My Advisors