THE USE OF ANISOTROPIC PARTICLE DISPERSIONS FOR THE FABRICATION OF FLEXIBLE SHEAR-THICKENING FLUID/KEVLAR FABRIC COMPOSITES

R. G. Egres, Jr. (PhDChE), E. D. Wetzel (ARL), and N. J. Wagner

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

MOTIVATION

Impregnating Kevlar fabric with shear-thickening fluid (STF) can significantly enhance its response to ballistic impact, which could lead to the development of improved flexible body armor systems.* As a possible low-cost alternative to silica (spherical) particle shear-thickening suspensions, anisotropic precipitated calcium carbonate (PCC) suspensions were investigated to determine whether they could impart improve ballistic performance or weight reduction to STF/Kevlar ballistic composites.

RESEARCH OBJECTIVES

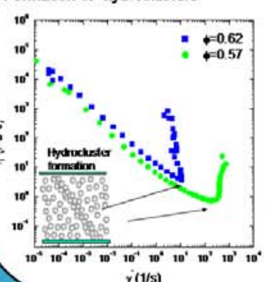
1. Investigate how particle anisotropy affects the rheology of concentrated PCC colloidal dispersions:
   - critical stress at the shear thickening transition
   - critical volume fraction for extensive (discontinuous) shear thickening
   - change in microstructure during shear thickening
2. Conduct fragment simulation projectile (FSP) ballistic testing of Kevlar fabric composite targets containing anisotropic particle STF at several particle loadings.
   - can anisotropic particle STF provide improved energy dissipative response at lower particle loadings?

* Y. S. Lee, E. D. Wetzel, N. J. Wagner, *J. Mater. Sci.* 38 (2003) 2825

ENERGY DISSIPATION IN KEVLAR/SHEAR-THICKENING FLUID COMPOSITES

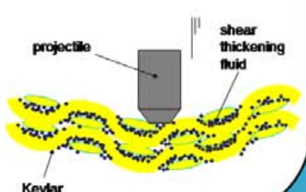
Shear Thickening Suspensions

- Shear thickening results when hydrodynamic lubrication forces overcome repulsive interparticle forces
- Formation of "hydroclusters"



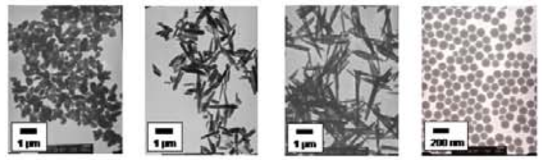
Kevlar/STF Impact event

- Ballistic event deforms composite
- Fiber pull-out and deformation induce shear thickening response
- Shear thickening results in enhanced friction and energy dissipation in composite



RHEOLOGY

Suspensions of PCC in polyethylene glycol having three different particle aspect ratios were produced and tested using a rheometer



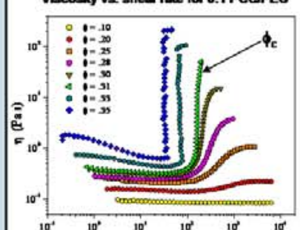
2:1 PCC particles
length: 628 ± 226 nm
diameter: 328 ± 122 nm
l/d: 1.92 ± .47

4:1 PCC particles
length: 1012 ± 434 nm
diameter: 255 ± 78 nm
l/d: 4.02 ± 1.30

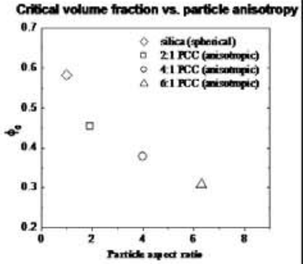
6:1 PCC particles
length: 1360 ± 554 nm
diameter: 220 ± 77 nm
l/d: 6.39 ± 2.26

silica particles
diameter: 120 nm
(spherical)

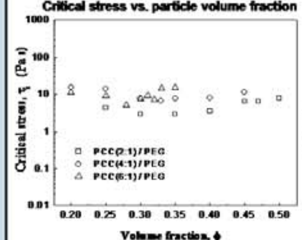
Viscosity vs. shear rate for 6:1 PCC/PEG



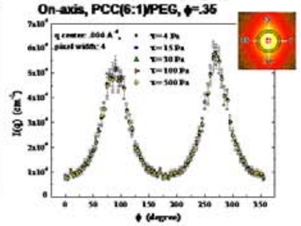
Critical volume fraction vs. particle anisotropy



Critical stress vs. particle volume fraction



Rheo-SANS (annular averaged)
On-axis, PCC(6:1)/PEG, ϕ=.35



- Anisotropic PCC/PEG suspensions exhibit discontinuous shear thickening.
- Critical volume fraction for discontinuous shear thickening, ϕ_c, decreases with increasing particle aspect ratio.
- Critical stress for shear thickening in PCC/PEG dispersions is not influenced by particle anisotropy. τ_c possibly scales with particle diameter dimension
- Rheo-SANS (small angle neutron scattering) demonstrates long-axis particle alignment with flow direction is maintained during shear thickening.

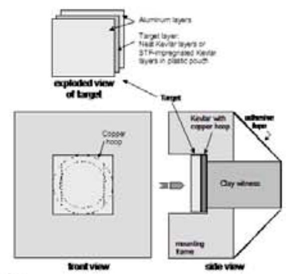
BALLISTIC IMPACT TESTING

Dissipated Energy Calculation

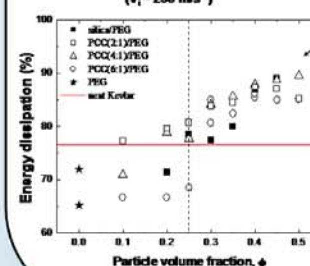
$$E = \tfrac{1}{2} m_p (V_i^2 - V_r^2)$$

E: dissipated kinetic energy
m_p: projectile mass
V_i: initial projectile velocity
V_r: residual velocity, calculated from depth penetration into clay witness

Experimental Set-up



Ballistic results of 4 Kevlar layer targets with 2 ml of STFs at several particle loadings, (V_i ~ 250 m/s)



- Improved energy dissipation over neat Kevlar is observed in all composites when STF particle loadings are above ϕ =0.25
- Anisotropic particle STF targets demonstrate improvement over silica STF targets for loadings between ϕ =0.25 and ϕ =0.40
- For particle loadings below ϕ =0.25, target ballistic energy dissipation is lower than that of 4 layers of neat Kevlar

CONCLUSIONS

- Critical volume fraction for discontinuous shear thickening transition is reduced as particle anisotropy (aspect ratio) is increased
- Kevlar composite targets containing anisotropic PCC/PEG STFs demonstrate improved ballistic performance at lower particle loadings than observed in silica STF composites

FUTURE WORK

- Investigate ballistic performance of Kevlar/ anisotropic STF composites at higher impact velocities

ACKNOWLEDGEMENTS

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