BALLISTIC PERFORMANCE OF KEVLAR®/SHEAR THICKENING FLUID COMPOSITES

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TECHNOLOGICAL GOAL

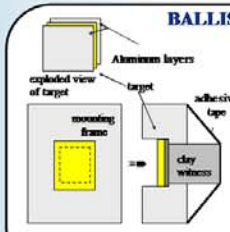
- Fill the need for **flexible body armor**
- Currently fielded body armor systems employ multi-ply Kevlar® fabric armors, whose bulk and stiffness make them practical only for torso protection.
- Ballistic protection for extremities requires **lightweight, flexible body armor** without significantly compromising mobility and dexterity.

LIQUID ARMOR FOR PERSONAL PROTECTION

- Investigate the ballistic properties of Kevlar fabrics impregnated with colloidal shear thickening fluids (STFs)
  - STFs undergo a sudden and dramatic increase in viscosity above a critical shear rate, in some cases transforming to a material that exhibits solid-like behavior
- Results in a composite which is flexible at low strain rates, such as during normal motion, but stiffens upon sudden impact to provide ballistic protection
- Yields significantly **better flexibility** and **reduced weight** when compared to equally performing neat Kevlar

- Areas currently protected by INTERCEPTOR Body armor system
- Not protected with body armor due to flexibility constraints

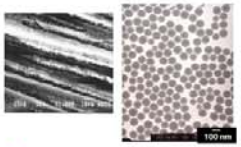
BALLISTIC EXPERIMENTAL SETUP



Ballistic test frame and target geometry

- Targets
  - Impregnate Kevlar with STF
  - Encapsulate impregnated Kevlar in polyethylene film
  - Sandwich target between aluminum foil faces
  - 2"x2" in size
- Ballistic tests
  - 0.22 cal FSP (Fragmentation Simulation Projectile)
  - Clay witness
    - Quantify ballistic performance in terms of depth of penetration
    - Use clay ballistic curves to relate penetration depth in energy absorbed by target

SHEAR THICKENING FLUID (STF)



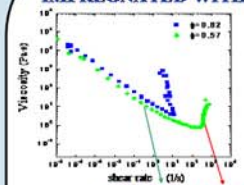
- Nissan Chemicals MP4540, 120 nm diameter silica particle (determined by dynamic light scattering and TEM)
- Silica particles were dispersed in polyethylene glycol (PEG)

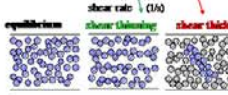
- SEM image shows evidence of silica particles located between the yarns as well as impregnation into the fiber tows

KEVLAR

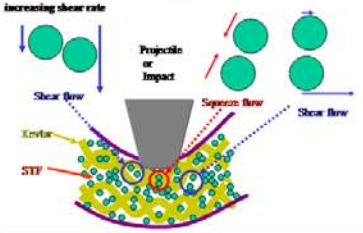
- Plain-woven Hexcel Aramid Style 706 (Kevlar KM-2, 600 denier)
- 13.386 yarns/cm, areal density 180 g/m2

ENERGY DISSIPATION MECHANISM OF KEVLAR IMPREGNATED WITH SHEAR THICKENING FLUID

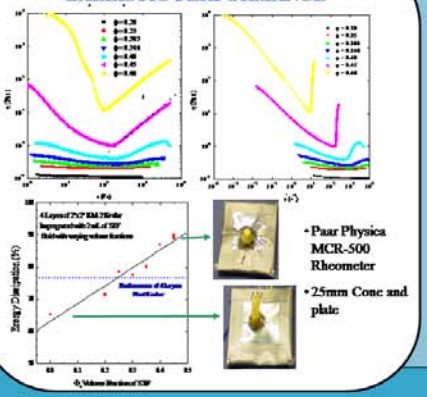




- Liquid phase highly filled with rigid, colloidal particles
- At high shear rates, hydrodynamic forces overcome repulsive interparticles forces, and hydroclusters form
- Particles collide, material becomes macroscopically rigid



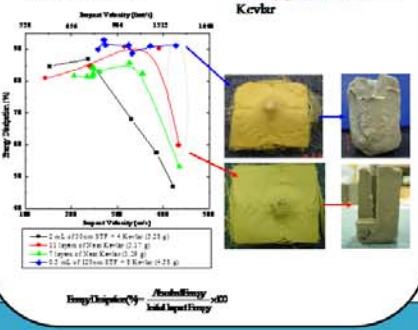
RELATING RHEOLOGY OF STF TO BALLISTIC PERFORMANCE



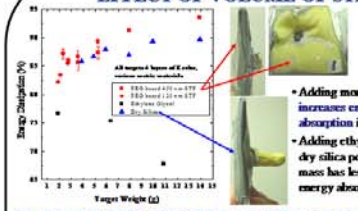
- Paar Physica MCR-500 Rheometer
- 25mm Cone and plate

HIGH VELOCITY PERFORMANCE

- Increasing the number of fabric layers increases the high velocity performance
- STF-Kevlar at high fabric loadings offers superior high velocity performance to neat Kevlar

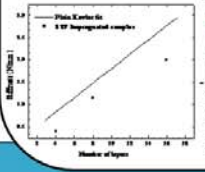


EFFECT OF VOLUME OF STF



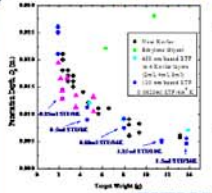
- Adding more STF increases energy absorption in target
- Adding ethylene glycol or dry silica powder of equal mass has less effect on energy absorption

FLEXIBILITY OF KEVLAR/STF COMPOSITES



- STF-impregnated Kevlar targets are lighter, thinner and more flexible than neat Kevlar targets with comparable ballistic performance
- Testing protocol for testing the flexibility of ballistic fabric composites is based on M. Miraihoun, M. Pagnan, G, and P. Vallee, "A new method for the measurement of the stiffness of ballistic fabrics" 31st Int. SAMPE Technical Conference, 1999.

PENETRATION DEPTH



- Penetration depth of clay witness as a function of number of Kevlar layer and the amount of shear thickening fluid
- Impact velocity approximately 800 fps (244m/s)

PUBLICATIONS

Lee Y.S.,Wetzel, E.D., Wagner, N.J., The ballistic impact characteristics of Kevlar woven fabrics impregnated with a colloidal shear thickening fluid. *J. Mat. Sci.* 38, 2825-2833 (2003)

Egres, R. G., Lee, Y. S., Kirkwood, J. E., Kirkwood, K. M., Wetzel, E. D., and Wagner, N. J., "Novel flexible body armor utilizing shear thickening fluid (STF) composites" The 14th International Conference on Composite Materials (ICCM-14), July 2003.

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