LIQUID BODY ARMOR BASED ON SHEAR-THICKENING FLUID

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CONCEPT AND OBJECTIVE OF LIQUID BODY ARMOR

- High strength fabric (*e.g.*, Kevlar) impregnated with shear-thickening fluid (*"shear-thickening nanocomposite"*)
  - Ballistic event deforms composite
  - Deformation induces shear-thickening effect in matrix fluid
  - Fabric helps distribute shear-thickening effect (and load transfer) over large area
  - ST fluid provides enhanced friction in composite
- Unique energy adsorption mechanisms of ST fluids

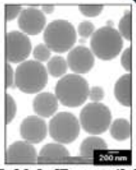
Research Objective

- Investigate the properties of Shear-Thickening Fluids through rheology and fiber pull-out tests
- To combine Kevlar and a Shear-Thickening Fluid into a more effective personal body armor

MATERIALS

Shear-thickening fluid

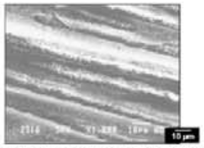
- Colloidal silica particles (avg particle size: ~450 nm or 120 nm)
- Ethylene glycol (EG) or polyethylene glycol (PEG) carrier fluid
- Advantages over water carrier fluid:
  - Wets Kevlar moderately
  - Environmentally stable
- Final particle concentration: 55-65 vol%



colloidal silica particles

Kevlar

- KM-2 Kevlar® fabric
  Style 706, 600 denier (180 g/m²)



STF-impregnated Kevlar fabric

Composite preparation

- Dilute STF with ethanol
- Wet diluted STF into Kevlar
- Evaporate ethanol in oven (80°C for 20 min)

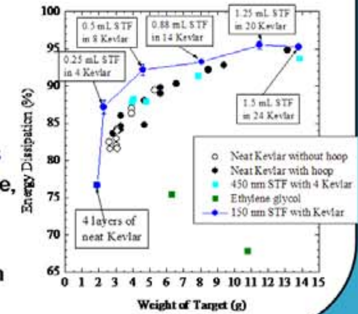
BALLISTIC EXPERIMENTS AND RESULTS

Targets

- Impregnate Kevlar with varying amounts, patterns, types of STF
- Encapsulate impregnated Kevlar in polyethylene film Sandwich target between aluminum foil faces
- 2"x2" in size

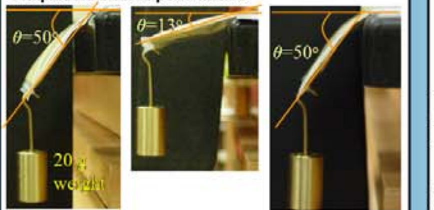
Ballistic tests

- 0.22 cal FSP
- Velocity ~ 825 fps
- Target set in frame, not clamped
- Clay witness for penetration depth



FLEXIBILITY / BULK OF STF-IMPREGNATED KEVLAR

- STF-impregnated Kevlar targets are lighter, thinner, and more flexible than neat Kevlar targets with comparable ballistic performance



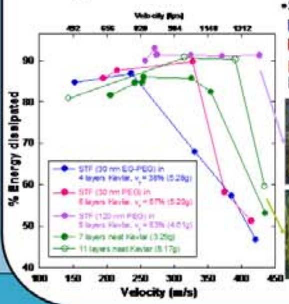
4-layer Kevlar: Thickness: 1.4 mm Weight: 1.9 g E_{diss}: 76.7%

10-layer Kevlar: Thickness: 3.0 mm Weight: 4.7 g E_{diss}: 86.7%

0.25 mL STF (120 nm) impregnated 4-layer Kevlar: Thickness: 1.4 mm Weight: 2.3 g E_{diss}: 87.2%

HIGH VELOCITY PERFORMANCE

- All targets reach critical velocity above which ballistic performance drops off drastically
- 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

MECHANISM OF BALLISTIC ENERGY ABSORPTION

- Mechanisms of energy absorption in conventional fabric armors
  1. Yarn pullout
  2. Fiber plastic deformation
  3. Fiber fracture
- Compare impacted targets
  (4 layers of Kevlar with and without STF)
  Less pullout in STF composite
  More fiber fracture in STF composite

unimpregnated Kevlar — STF-impregnated Kevlar

CONTINUING WORK

- **Particles**
  - Particle anisotropy
  - Particle size
  - Possibility for enhanced energy absorption mechanisms at very small particle sizes
  - Particle material -> polymeric, rubber particles lower density particles for reduced target weight
  - Softer particles for modification of energy absorption mechanisms particle surface energy
- **Fabric**
  - Denier
  - Weave
  - Fiber type

ACKNOWLEDGEMENTS

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