MODELING THE IMPACT OF FLEXIBLE TEXTILE COMPOSITES THROUGH MULTISCALE AND PROBABILISTIC METHODS

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RESEARCH OVERVIEW
ROLE OF MATERIALS AND ARCHITECTURE ON IMPACT PERFORMANCE
2D Vs. 3D architecture
Role of structural stitching and Z-tows
Effect of tow geometry and undulations
Effect of material properties (e.g. modulus, strength)

Computational Modeling of Fabric Impact
Fabric system studied: plain weave Kevlar S706 fabric
- Understand energy dissipating mechanisms: momentum transfer, internal energy, frictional interactions
- Finite element analysis using LS-DYNA
- Fabrics modeled using a yarn-level architecture

Multiscale Modeling of Fabric Impact
- Massive savings in the computational requirements of the FE model
- Enables simulation of large dimensioned multi-layer fabric panels
- Yarns modeled using both solid and shell elements
- 3 modeling levels – filament, yarn, membrane

Setup of 2D and 3D Fabric FE Models
- Micrographs used as input to DYNAFAB™
- Output is a FE model with a yarn level architecture

Multiscale Modeling Using the HEA Method
Hybrid Element Analysis (HEA) is defined as 'the finite element analysis of a structure by combining different finite element formulations at both a single and multiple scales of modeling'

Sample HEA Configurations
Central Patch HEA
Center Strip HEA
Central Cross HEA
Single Scale HEA

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PROBABILISTIC NATURE OF FABRIC IMPACT PERFORMANCE

- Parameters such as $V_0$, $V_{50}$, $V_{100}$ used to describe impact performance
- Probabilistic impact performance arises from two sources of variability:
  - Intrinsic: filament geometry (diameter) and packing, fabric architecture, yarn material properties (modulus, strength, frictional coefficient), et cetera.
  - Extrinsic: experimental equipment (gas gun, projectile, backing material), statistical techniques (Neyer-D, Langlie), testing conditions (fabric slippage, impact location), et cetera.

IMPORTANT QUESTIONS

- What is the relation between the statistical nature of yarn strength and the fabric probabilistic impact performance?
- How do the characteristics of the yarn strength distribution (mean, width, shape) affect the impact performance?
- What are the effects of weaving and scouring strength degradations on the impact performance?
- What are the effects of projectile characteristics (size, shape, trajectory) and fabric architecture (plain weave, structural stitching, 3D fabric) on the probabilistic impact performance?

EXPERIMENTAL AND NUMERICAL SETUP

Experimental setup

Numerical setup in LS-DYNA

Experimental Fabric Slippage

EXPERIMENTAL CHARACTERIZATION OF YARN STRENGTH – LENGTH SCALE EFFECTS

Cumulative Distribution Function (CDF) for a 3-parameter Weibull distribution with parameters $\alpha$ (scale), $m$ (shape), $x$ (threshold), length scale parameter $\alpha$ ($\alpha_1$ for $L < L_0$; and $\alpha_2$ for $L > L_0$)

$F(\sigma) = 1 - \exp\left( - \left( \frac{L}{L_0} \right)^m \left( \frac{(\sigma - x)}{\alpha} \right) \right)$

3-parameter Weibull and G-Gamma distributions used for the CDF

Warp yarns are degraded to higher levels than the fill yarns

EXPERIMENTAL CHARACTERIZATION OF YARN STRENGTH – WEAVING EFFECTS

NUMERICAL $V_0$-$V_{100}$ PREDICTIONS

2in. x 2in. Kevlar S706 fabric with spool based strength mappings held on four sides (zero slippage) and impacted by a 0.22 caliber spherical projectile

$F(\sigma) = 1 - \exp\left( - \left( \frac{L}{L_0} \right)^m \left( \frac{(\sigma - x)}{\alpha} \right) \right)$

NUMERICAL $V_0$-$V_{100}$ PREDICTIONS

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