A PARAMETRIC ANALYSIS OF THE QUASI-STATIC PENETRATION OF COMPOSITE MATERIALS

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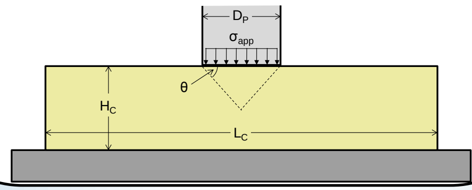
BACKGROUND & MOTIVATION

- Ballistic testing is a key empirical technique for understanding high strain rate penetration behavior
  - Testing many projectile-target pairs is intensive
  - Quasi-static (QS) methods can provide insights
- Gama & Gillespie (2008) developed a QS Penetration Method to predict ballistic behavior
  - Full testing requires a variety of span and punch diameters and specimen thicknesses
  - Use of scaling parameters could add predictive capabilities between projectile-target pairs
- Four damage regimes to consider:
  - **Confined Compression (Present Problem)**
  - Shear-Dominated Failure
  - Bending-Dominated Failure
  - Mixed Shear-Bending Behavior

PROBLEM PARAMETERS

- <u>Goals</u>: Develop ability to predict force at damage initiation for any geometry from a single QS test
- Five parameters (assuming uniform material)
  - Applied load, P_{app} (or stress, $P_{app}/A_P = \sigma_{app}$)
  - Plug Formation Angle, θ (constant)
  - Punch Diameter, D_P
  - Specimen Thickness, H_C
  - Specimen Width, L_C (should not affect scaling)
- Define a "thick" composite by formation of a full-depth shear plug (i.e. $H_C > ½ D_P \tan θ$)



ANALYTICAL SOLUTION

- Analytical forms show which problem parameters are important and how these parameters are related
- Use 2-D solution developed by D. Milovic (1992)
  - Assumes a uniform strip load at center of panel
- Three parameters (neglecting material properties):
  - Punch diameter; specimen width and thickness
- Solution form (shown for shear stress, τ_{xz})

$$\tau_{xz} = -\sigma_{app}\sum_{m=1}^{M}\frac{1.25\sin\frac{m\pi D}{2L}\left[2.40\times10^{9}\sinh\left(\frac{0.47m\pi H}{L}\right)\cosh\left(\frac{3.32m\pi z}{L}\right)-2.40\times10^{9}\sinh\left(\frac{3.32m\pi H}{L}\right)\cosh\left(\frac{0.47m\pi z}{L}\right)\right]\cos\frac{m\pi x}{L}}{m\pi\left[1.51\times10^{8}\sinh\left(\frac{0.47m\pi H}{L}\right)\cosh\left(\frac{3.32m\pi H}{L}\right)-1.44\times10^{9}\sinh\left(\frac{3.32m\pi H}{L}\right)\cosh\left(\frac{0.47m\pi H}{L}\right)\right]}$$

  - Note geometric ratios of D_P/L_C and H_C/L_C
  - Force term represented by applied stress, σ_{app}
- Scaling should involve a geometric ratio and the normalization of force by the area of the punch-head

SPECIMEN CRITICAL WIDTH

- There exists a critical specimen width L_{crit} beyond which additional material provides no added confinement
  - Define as radius where through-thickness stress on support is zero
- Calculated expressions for L_{crit}
  - "Thin": $L_{crit} = 0.94D_P + 2.47H_C$
  - "Thick": $L_{crit} = 0.37\left(\frac{D_P}{H_C}\right)D_P + 3.11H_C$
- Can show that stress distributions are the same for $L_C > L_{crit}$

GEOMETRIC SCALING

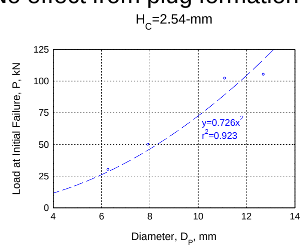
- Assuming that $L_C = L_{crit}$, ratios of D_P/L_C and H_C/L_C can be simplified to D_P/H_C

$$\text{e.g.: } \frac{H_C}{L_{crit}} = \frac{H_C}{0.94D_P + 2.47H_C} = \frac{1}{0.94\left(D_P/H_C\right) + 2.47}$$

- If two projectile-target pairs have the same D_P/H_C, stresses will be the same
- Use ratio as a measure of the "relative thickness" of a specimen
  - From measured plug formation angle define $(D_P/H_C)_{crit} = 1.37$ as boundary between "thin" and "thick" specimens (e.g. "thick": $D_P/H_C < 1.37$)

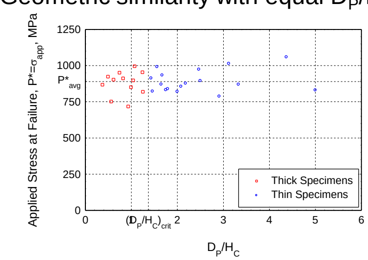
EXPERIMENTAL RESULTS

- Plot peak force against key parameters
  - Force is quadratic as diameter increases, constant with thickness
  - Validates scaling with punch area
  - No effect from plug formation type



CONCLUSIONS

- Scale peak force with punch area
- Geometric similarity with equal D_P/H_C



ACKNOWLEDGEMENTS

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