Validation of Puncture Simulations with Various Probe Geometries

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Project Overview

- **Goals:**
  - Determine the effect that differing probe geometries have on the energy required to puncture AA7075-T651 and SS304L plates

- **Technical Approach:**
  - Calibrate Johnson-Cook plasticity and failure model to experimental results for AA7075-T651
  - Select plasticity and failure model for SS304L simulations
  - Simulate three differing probe geometries impacting two different coupon geometries for both AA7075-T651 and SS304L
AA7075-T651 Coupon and Probe Geometries

(a) Hemispherical Probe
(b) Flat Probe
(c) Corner Probe

Thin AA7075-T651 Coupon
Thick AA7075-T651 Coupon

Dimensions in Millimeters
SS304L Coupon and Probe Geometries

(a) Hemispherical Probe
(b) Flat Probe
(c) Corner Probe

Thin SS304L Coupon
Thick SS304L Coupon

Dimensions in Millimeters
The thin aluminum coupon is 1.65 mm thick.

The energy absorbed by the coupon for three different probes were evaluated; Flat probe, Corner probe, Hemispherical probe.

Plasticity Model: Johnson-Cook (Corona et al)
\[ \sigma = \left[ A + B \varepsilon_p^n \right] \left[ 1 + C \ln(\dot{\varepsilon}^*) \right] \left[ 1 - T^*m \right] \]

Damage Model: Johnson-Cook (Brar et al)
\[ \varepsilon^f = (D_1 + D_2 e^{D_3 \sigma^*}) (1 + D_4 \ln \dot{\varepsilon}^*) (1 + D_5 T^*) \]

Initial Total Probe Kinetic Energy: 200 J


Flat Probe is Close to Experimental Results

- ~16% difference in energy absorbed between experiments and the model
- Reduction in velocity of the probe in the model is within ~7.6% of experimental data

Fracture surface of flat probe experiment

Flat probe model crack propagation

![Graph showing energy absorbed between experiment and model](image)
Corner Probe Model Fracture Surface Resembles Experimental Fracture Surface

- ~158% difference in energy absorbed between experiments and the model
- Reduction in velocity of the probe in the model is within ~61% of experimental data

Fracture surface of corner probe experiment

Corner probe model crack propagation
$V_o = 1.69 \frac{m}{s}$
AA7075-T651 Thick Coupon Boundary Conditions

- The thin aluminum coupon is 6.25 mm thick (0.25”)
- Initial Probe Kinetic Energy: 450 J
- Plasticity Model: Johnson-Cook (Corona et al)
  \[ \sigma = [A + B\epsilon_p^n][1 + Cln(\dot{\epsilon}^*)][1 - T^{*m}] \]
- Damage Model: Johnson-Cook (Brar et al)
  \[ \epsilon^f = (D_1 + D_2 e^{D_3 \sigma^*})(1 + D_4 ln \dot{\epsilon}^*)(1 + D_5 T^*) \]
- Failure Criterion: Equivalent Plastic Strain 0.2


Flat

Corner

$V_o = 3.6 \frac{m}{s}$

Hemi

$V_o = 3.6 \frac{m}{s}$

6.35 mm Thick Aluminum 7075-t651

Energy Absorbed (J) vs. Time (ms):
- Flat (577 J)
- Corner (774 J)
- Hemi (701 J)
- Puncture
Thick Aluminum Plate Experimental Results Comparison (Corner Probe)

- ~102% difference in energy absorbed between experiments and the model
- Reduction in velocity of the probe in the model is within ~42% of experimental data

![Energy Absorbed (J) diagram](chart.png)
1.60 mm Thick SS304L Coupon

- Plasticity Model: BCJ (Horstemeyer et al)
- Damage Model: Max eqps (Blandford et al)
- Coupon Mesh Quality: 0.83
- Flat Probe Initial KE: 1000 J
- Corner Probe Initial KE: 1000 J
- Hemi Probe Initial KE: 2000 J

Mesh Refinement Study

Elements: 365,720
Hourglass Energy: 8398 J
Probe $\Delta KE$: 397.2 J

Elements: 387,770
Hourglass Energy: 1005 J
Probe $\Delta KE$: 1764 J

Elements: 969,200
Hourglass Energy: 224.5 J
Probe $\Delta KE$: 1753 J
Mesh Refinement Study (Cont.)

3.2 mm thick 304L Steel Coupon, BCJ

Mesh refinement results in a \textit{314 \%} increase in energy

1.6 mm thick 304L Steel Coupon, BCJ

Mesh refinement results in a \textit{212 \%} increase in energy
$V_o = 3.78 \frac{m}{s}$

$V_o = 5.35 \frac{m}{s}$

$V_o = 3.78 \frac{m}{s}$
3.20 mm Thick SS304L Coupon

- Plasticity Model: BCJ (Horstemeyer et al)
- Damage Model: Max eqps (Blandford et al)
- Coupon Mesh Quality: 0.85
- Flat Probe Initial KE: 2400 J
- Corner Probe Initial KE: 2400 J
- Hemi Probe Initial KE: 4800 J

$V_0 = 5.86 \frac{m}{s}$

$V_0 = 8.29 \frac{m}{s}$

$V_0 = 5.86 \frac{m}{s}$

3.20 mm Thick 304L Steel Coupon

Energy Absorbed (J)

Time (ms)
Conclusion AA7075-T651

- Johnson-Cook plasticity and failure models were used to simulate puncture of various Al 7075-T651 coupons
- Simulations consistently over-predict energy absorbed when compared to experimental results, most notably for corner-probe geometry
- Regardless of thickness, simulations consistently show the following trend in energy absorbed:
  - High -> Corner Probe
  - Medium -> Hemi Probe
  - Low -> Flat Probe

![Energy Absorption Graph](Image)
Conclusion SS304L

- BCJ plasticity model with eqps failure criteria was used
- Hemispherical probe absorbs much more energy due to high ductility of steel and few areas of stress concentration
- Dominating failure modes change with coupon thickness
- For 304L Steel, primary mechanism of energy absorption for each probe are as follows:
  - Flat -> Plastic Strain Energy
  - Corner -> Fracture Energy
  - Hemi -> Plastic Strain Energy
Future Work

- Calibrate failure model for SS304L
- Compare SS304L models to experimentation
- Further evaluate the role that thickness of the coupon has on energy absorption for each probe
- Evaluate probe orientation’s affect on puncture energy
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Corner Probe Requires Highest Energy for Fracture

- Corner Probe and Hemispherical Probe requires largest energy for fracture
  - Due to increase contact surface
- Flat Probe requires least energy input for fracture