Modeling and Testing of Ceramic Armor
Tile Survivability to Fragment Attack

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Outline

• Research objectives
• Experimental setup and results
• Simulation modeling
• Discussion
• Summary & Conclusions
Research Objectives

• Modeling a ceramic (Al$_2$O$_3$) armor as an IM shield against fragment attack.
• Comparing simulations data to the corresponding tests results.
Test Setup

- OFHC Copper Fragment (18.6[g])
- Alumina tile (98% Al₂O₃)
- SS 304L backing

Dimensions:
- Ø87
- 150
- 50
- 17
Fragment formation

- Fragment is formed from the initiation of an EFP charge.
- An EFP charge is an explosive charge, consists of a metal casing and a 18.6 [gr] copper liner (acc. to STANAG 4496).
- After the initiation, the copper liner transforms into a hemispheric shaped fragment.
- Fragment’s K.E≈30KJ
- 0.5” AP K.E≈16KJ
Detailed Experimental setup

High speed camera (~47,000 fps)

Wooden Plate

Rear Shield

SS304 Backing

Alumina tile

450 [kv] X-Ray

Mirror

Steel shield plates

EFP charge

Initiation signal

60 cm
X-Ray

- A 450 [kv] Scandiflash X-Ray was used in order to examine the penetration process.
- 1st exp. flash time: 206 μs
- 2nd exp. flash time: 210 μs
- Parallax ratio = 0.83

Fragment during penetration

Alumina tile

Steel backing
Experiments Results – cont.

206μs

210μs
Experiments Results

• Two Experiments were conducted.
• 1\textsuperscript{st} experiment D.O.P. = 3.4 [mm]
• 2\textsuperscript{nd} experiment D.O.P. = 3.7 [mm]
Simulation Methods

• Autodyn v6.1 2D Lagrange solver has been used.
• Grid size convergence graph was done in order to optimize grid size and results convergence with computing resources.
• Parametric simulations were conducted, in order to evaluate different parameters and compare different constitutive models.
• Finally, fine grid size simulations were conducted on the chosen set of parameters.
# Simulation Modeling - Materials

<table>
<thead>
<tr>
<th>Part</th>
<th>Material</th>
<th>Equation of state</th>
<th>Strength Model</th>
<th>Failure Model</th>
<th>Source</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ceramic Tile</td>
<td>Alumina (98%)</td>
<td>Polynomial</td>
<td>Johnson Holmquist</td>
<td>Johnson Holmquist</td>
<td>Westerling and Lundberg (1995)</td>
</tr>
<tr>
<td>Fragment</td>
<td>Copper</td>
<td>Linear</td>
<td>Johnson Cook</td>
<td>Johnson Cook</td>
<td>Johnson and Cook (1985)</td>
</tr>
<tr>
<td>Backing</td>
<td>SS304</td>
<td>Shock</td>
<td>Steinberg Guinan</td>
<td>-</td>
<td>Steinberg (1991)</td>
</tr>
</tbody>
</table>
Simulated fragment penetration-
Half problem
Alumina Modeling- J-H strength model

- Parameters that were investigated: Fractured Curve
  - $B$ – slope of fractured curve
  - $\sigma^f_{\text{MAX}}$ - dimensionless fractured strength upper limit $|@D=1$

\[ \sigma_F^* = \text{MIN} \left[ B \left( \frac{P^*}{P} \right)^m \left( 1 - C \ln \epsilon^* \right) \sigma_F^{\text{MAX}} \right] \]
Parametric Simulations results

Chosen sets of parameters for the fine grid size simulation.

Experiment Results

B- Slope of fractured curve

σ_f^{max} = 0.3
σ_f^{max} = 0.5
σ_f^{max} = 0.6

DOP [mm]
<table>
<thead>
<tr>
<th>Source</th>
<th>Alumina</th>
<th>Code</th>
<th>$B$</th>
<th>$\sigma_{f_{\text{max}}}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Westerling et al. (1995)</td>
<td>99.7%</td>
<td>AUTODYN 2D (Lagrange)</td>
<td>0.77</td>
<td>0.5</td>
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<tr>
<td>Anderson et al. (1995)</td>
<td>99.5%</td>
<td>EPIC (SPH)</td>
<td>0.28</td>
<td>1</td>
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<tr>
<td>Lynch et al. (2006)</td>
<td>97.5%</td>
<td>Grim 2D (Euler)</td>
<td>0.86</td>
<td>0.5</td>
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<tr>
<td>Present work</td>
<td>98%</td>
<td>AUTODYN 2D (Lagrange)</td>
<td>0.77 Or 2</td>
<td>0.6</td>
</tr>
</tbody>
</table>
Discussion

- Original J-H model (JH2) gives good estimation of the D.O.P experimental results.
- For an exact match, a modification of the fractured material parameters is presented ($\sigma_{\text{max}}^f$, B).
- The ‘$\sigma_{\text{max}}^f$’ Parameter has a strong influence on the D.O.P results. Nevertheless, ‘B’ parameter doesn’t show a directional trend.
Summary & Conclusions

- Two firing experiments were conducted in order to acquire D.O.P results.
- Experimental D.O.P results were compared to the corresponding simulations results.
- Simulations were carried out using Autodyne v6.1 2D Lagrange solver.
- A set of parameters were chosen (JH2 model) in order to match the experimental results.
Future work...

• Further experiments on the same armor:
  • 1600 [m/s] fragment
  • 2500 [m/s] fragment
  • Bullet Impact

• Weight optimization (backing) for the armor is needed for commercial use.
The End