Modeling of Fracture in AHSS Component Crush Tests

Guofei Chen
United States Steel Corporation
Contribution

Ford Motor Company
• Tau Tyan

United States Steel Corporation
• Ming F. Shi
• Todd M. Link
• Aleksy Konieczny
Overview

- Introduction
- Crush Tests
- Material Models
- Simulations and Validations
- Conclusions
Introduction

- In recent years, AHSS have been widely accepted as the material of choice to reduce vehicle weight and improve vehicle’s structural performance;
- Crash simulations not taking into account the fracture behavior may overstate load-carrying capacity and energy absorption;
- It is important to develop the capability to predict the fracture behavior correctly in crash simulations and to accurately assess AHSS designs in the vehicle development process;
- Five material fracture models available in LS-Dyna are adopted to simulate the fracture behavior of DP590 and DP780 steels in crush loadings. The capability of the five material fracture models for the fracture prediction is assessed.
Crush Tests

DP780 – Quasi-static Bending

DP590 – 15mph Axial
## Material Failure Models in LS-Dyna

<table>
<thead>
<tr>
<th>Failure Criterion</th>
<th>Dependency of</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Load path</td>
</tr>
<tr>
<td><strong>MAT24</strong></td>
<td>yes</td>
</tr>
<tr>
<td>$\varepsilon_f \leq \varepsilon_{pf}$</td>
<td></td>
</tr>
<tr>
<td><strong>MAT123</strong></td>
<td>yes</td>
</tr>
<tr>
<td>$\varepsilon_1 \leq \varepsilon_{1f}$</td>
<td></td>
</tr>
<tr>
<td><strong>MMC Model</strong></td>
<td>yes</td>
</tr>
<tr>
<td>$\varepsilon_f = \left{ \frac{A}{c_2} f_3 \left[ \left( \frac{1+c_1^2}{3} \cdot f_1 \right) + c_1 \left( \frac{-q + f_2}{3} \right) \right] \right}^{\frac{1}{r}}$</td>
<td></td>
</tr>
<tr>
<td><strong>MAT15,224</strong></td>
<td>yes</td>
</tr>
<tr>
<td>Johnson-Cook</td>
<td></td>
</tr>
<tr>
<td>$\varepsilon_f = \left[ D_1 + D_2 \exp D_3 \sigma^* \right] \left[ 1 + D_4 \ln \varepsilon^* \right]$</td>
<td>yes</td>
</tr>
<tr>
<td><strong>MAT120</strong></td>
<td>yes</td>
</tr>
<tr>
<td>Gurson</td>
<td></td>
</tr>
<tr>
<td>$\Phi = \frac{\sigma_M^2}{\sigma_y^2} + 2q_1 f^* \cosh \left( \frac{3q_2 \sigma_M}{2\sigma_y} \right) - 1 - \left( q_1 f^* \right)^2 = 0$</td>
<td>yes</td>
</tr>
</tbody>
</table>
Fracture Criteria – MAT24 and MAT123

MAT24: Fracture may occur when the stress state is in compression
MAT123: Fracture when the major strain reaches the failure limit
Both MAT24 and 123 are not dependent on the stress state
A minimum of three tests are needed to calibrate the three fracture-related material parameters $c_1$, $c_2$ and $c_3$:
- the equi-biaxial punch fracture test
- the transverse plane strain fracture test
- the shear fracture test
MMC and JC Fracture Locus – DP590 and DP780

DP590

Stress Triaxiality

Stress Triaxiality

Equivalent strain to failure

Equivalent strain to failure

MMC

JC

Test

MMC

JC

Test
In Gurson Model, growth of existing void depends only on the hydrostatic stress:

\[ \dot{f}_G = (1 - f) \dot{\varepsilon}^{pl}_{kk} \]

Shear Test on DP590

Gurson Model

Johnson-Cook Model
Incremental Forming Simulation – MMC Model

Mapped Results:
- Thickness
- Plastic strain
- Strain components
- Damage parameter
Number of Integration Points – MMC Model

Through-Thickness

Crush Force (kN) vs. Displacement (mm) for different integration points:

- A: Test Average
- B: 3 Points
- C: 5 Points
- D: 7 Points
- E: 9 Points

Graph showing the comparison of crush force over displacement for different numbers of integration points.
Mesh Size Sensitivity – MMC Model

15 mph Axial Crush – DP590

Test

Mesh – 3 mm

Mesh – 2 mm

Mesh – 1 mm
Uniaxial Tensile Test on DP590 – MMC Model
Quasi-Static Bending Crush – DP780
Comparison of Failure Models

Test

MAT 24

MAT 123

MMC Model

Gurson Model

JC Model
Quasi-Static Bending Crush
Comparison of Failure Models

![Graph showing comparison of failure models](www.autosteel.org)

- A. Test Average
- B. MAT24
- C. MAT123
- D. MMC Model
- E. MAT120 - Gurson
- F. MAT224 - JC Model
Quasi-Static Bending Crush – MMC Model

Forming Effect

Cracks on Outer

Test

Cracks on Inner

With Forming

W/O Forming

Outer

Inner
Damage Parameter D – MMC Fracture Model
Quasi-Static Bending Crush Load
MMC Fracture Model
15 mph Axial Crush – DP590
Comparison of Failure Models

- Test
- MAT 24
- MAT 123
- MMC Model
- JC Model
- Gurson Model
Forming Effect – MMC Model

Test

15 mph Axial Crush – DP590

With Forming

W/o Forming
15 mph Axial Crush
Comparison of Failure Models

- A. Test Average
- B. MAT123
- C. MMC Model
- D. MMC - w/o Forming
- E. MAT120-Gurson Model
- F. MAT224-JC Model

Crush Force (kN)

Displacement (mm)
15 mph Axial Crush – At the Tip

Test

MMC Fracture Model

MAT 123
Gurson Model with Johnson-Cook Failure Criterion – *MAT_GURSON_JC

To enhance the Gurson Model for shear-dominated loadings, Johnson-Cook failure criterion is added for stress triaxiality $\eta$ between pure shear and uniaxial tension:

$\eta > L_2$: Gurson

$L_2 \leq \eta \leq L_1$: Gurson and JC

$\eta < L_2$: Gurson
15 mph Axial Crush – Gurson_JC Model

Test

15 mph Axial Crush – DP590

Gurson_JC Model

Gurson Model
Conclusions

- The MMC model performed well in fracture predictions for both the bending and axial crush tests conducted in this study.
- Johnson-Cook model MAT224 and MAT123 gave a good prediction in the bending crush and a reasonably good prediction in the axial crush.
- Gurson model MAT120 enhanced with Johnson-Cook failure criterion was able to capture the fracture mode at the corners in the axial crush.
- MAT24 could not capture the fracture mode in the axial crush and should be avoided in fracture prediction for deformation with complicated loading paths.
- For bending crush, the consideration of forming results in the crush simulation had no effect on the fracture mode but some effect on crash force predictions.
- For the axial crush simulation, the forming effect must be considered in the crush simulation since the forming results had a significant influence on the fracture mode and the crash force predictions.