Elastic Plastic Fracture Analysis of an Aluminum COPV Liner

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Abstract: Onboard any space-launch vehicle, composite over-wrapped pressure vessels (COPVs) may be utilized by propulsion or environmental control systems. The failure of a COPV has the potential to be catastrophic, resulting in the loss of vehicle, crew or mission. The latest COPV designs have reduced the wall-thickness of the metallic liner to the point where the material strains plastically during operation. At this time, the only method to determine the damage tolerance lifetime (safe-life) of a plastically-responding metallic liner is through full-scale COPV testing. Conducting tests costs substantially more and can be far more time consuming than performing an analysis. As a result of this cost, there is a need to establish a qualifying process through the use of a crack growth analysis tool. This paper will discuss fracture analyses of plastically responding metallic liners in COPVs. Uni-axial strain tests have been completed on laboratory specimens to collect elastic-plastic crack growth data. This data has been modeled with the crack growth analysis tool, NASGRO 6.20 to predict the response of laboratory specimens and subsequently the complexity of a COPV.

Keywords: COPV; elastic-plastic; fracture
Elastic-Plastic Fracture Analysis of an Aluminum COPV Liner

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University of Colorado
Aluminum Liner

- Spun-form 6061 aluminum
- Specimens taken from sheet
- Uni-axial test data shown herein
- COPV testing not shown
- Data generated at NASA Langley Research Center (Dawicke, Lewis)
- Analysis performed at NASA Johnson Space Center
Stress Strain Response

6061 Aluminum
Room Temp, Lab Air

Stress (ksi) vs. Strain (inch/inch)
## Material Characterization

<table>
<thead>
<tr>
<th>Thickness</th>
<th>Yield (ksi)</th>
<th>Ultimate (ksi)</th>
<th>Young's Modulus (Msi)</th>
<th>Alpha (R-O)</th>
<th>R-O Exponent</th>
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</thead>
<tbody>
<tr>
<td>0.032</td>
<td>43.4</td>
<td>48.3</td>
<td>10.041</td>
<td>0.002</td>
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<tr>
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<td>45.7</td>
<td>10.020</td>
<td>0.002</td>
<td>25</td>
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<td>0.090 Lot 1</td>
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<td>47.2</td>
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<tr>
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<td>48.9</td>
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<tr>
<td>0.125</td>
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<td>50.41</td>
<td>9.887</td>
<td>0.002</td>
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</tr>
</tbody>
</table>
Crack Growth Rate

NASGRO EQN curve for M6AB13AB1
6061-T6 Plt; T-L

Curve parameters (values shown a changed from orig matl file valu
C=8.5e-09, n=3, p=0, q=0
Yield=41
Kc=46.2014, Klc=27, Ak=1, Bk=0
DK1=1.31, Cth=1.5

03 Aug 2012, NASGRO(R) v6.21 , Copyright(c) 2012 SwRI(R). All rights reserved.
This version of NASGRO(R) is limited to official NASA, ESA, and FAA business only. All other uses prohibi
Elastic-Plastic Fracture Mechanics

- NASGRO 6.2 EPFM module

<table>
<thead>
<tr>
<th>Crack ID</th>
<th>Test Parameters</th>
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<tr>
<td>UNI 050 35 4</td>
<td>0.0205</td>
</tr>
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<td>UNI 050 35 5</td>
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<tr>
<td>UNI 090 35 1</td>
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<tr>
<td>COPV 090 35 2</td>
<td>0.0210</td>
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<tr>
<td>COPV 090 35 3</td>
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<td>COPV 090 36 1</td>
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<table>
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<tr>
<th>Crack ID</th>
<th>NASGRO Input: Specimen Geometry</th>
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<td>MT 3</td>
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</tr>
</tbody>
</table>
Comparison of Test and Analytical Crack Growth
UNI-125-35-3

2c (inch)

Cycles

Visual
NASGRO (ai=.0264)
NASGRO (ai=.030)
0.125” Fracture Surface

- 0.049 inch
- 0.030 inch
- \( a/c = 1.07 \)
- \( a/c = 1.36 \)
- 0.044 inch
- 0.092 inch
0.090” Uniaxial Test Data

Comparison of Test and Analytical Crack Growth
COPV-090-35-3

2c (inch)

Cycles

Visual
NASGRO (ai=.024)
NASGRO (ai=.034)
0.090” Fracture Surface
0.050” Uniaxial Test Data

Comparison of Test and Analytical Crack Growth
UNI-050-35-04

- Visual
- NASGRO (a=0.0246)
- NASGRO (a=0.028)
0.050” Fracture Surface
Token Promising Result

- Ductile Fracture
- Fatigue
- Precrack
- Notch

Measurements:
- 0.040 in.
- 0.067 in.
- 0.037 in.
- 0.026 in.

a/c values:
- a/c = 1.1
- a/c = 1.3

Date: 1/14/2008
Promising Analytical Result

0.05" Thick

Comparison of Test and Analytical Crack Growth UNI-050-35-1

- Visual
- NASGRO (a=0.024)
- NASGRO (a=0.026)
Summary

• Elastic plastic fracture analyses

Pros:
  – Results are promising when crack is self-similar
  – Additional testing needed to verify approach
  – Long-term goal of analytical certification

Cons:
  – Material data is difficult to obtain and reduce for NASGRO input
  – Stress input is not consistent with strain-controlled COPV liner

• Forward work
  – NASA is funding an upgrade to the EPFM module
  – EPFM testing is being performed for flight vehicles