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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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
## 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>
</tr>
</thead>
<tbody>
<tr>
<td>0.032</td>
<td>43.4</td>
<td>48.3</td>
<td>10.041</td>
<td>0.002</td>
<td>50</td>
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<tr>
<td>0.050</td>
<td>37.5</td>
<td>45.7</td>
<td>10.020</td>
<td>0.002</td>
<td>25</td>
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<tr>
<td>0.090 Lot 1</td>
<td>39.5</td>
<td>47.2</td>
<td>9.986</td>
<td>0.002</td>
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<td>0.090 Lot 2</td>
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<td>48.9</td>
<td>9.708</td>
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<td>50</td>
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<tr>
<td>0.125</td>
<td>46.63</td>
<td>50.41</td>
<td>9.887</td>
<td>0.002</td>
<td>30</td>
</tr>
</tbody>
</table>
Crack Growth Rate

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

Curve parameters (values shown are changed from original file values:
C=8.5e-09, n=3, p=0, q=0
Yield=41
Kc=46.2014, Klc=22, Ak=1, Bk=0
Dk=1.31, Cth=1.5

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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>Crack Length, c</th>
<th>Crack Depth, a</th>
<th>Crack Ratio, a/c</th>
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<tr>
<td>UNI 050 35 1</td>
<td>0.0200</td>
<td>0.0260</td>
<td>1.3000</td>
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<td>UNI 050 35 4</td>
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<td>1.3659</td>
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<tr>
<td>UNI 050 35 5</td>
<td>0.0205</td>
<td>0.0260</td>
<td>1.2683</td>
</tr>
<tr>
<td>UNI 090 35 1</td>
<td>0.0205</td>
<td>0.0340</td>
<td>1.6585</td>
</tr>
<tr>
<td>COPV 090 35 2</td>
<td>0.0210</td>
<td>0.0350</td>
<td>1.6667</td>
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<td>1.7000</td>
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<td>0.0120</td>
<td>0.2400</td>
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<tr>
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<td>1.3636</td>
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</tbody>
</table>

NASGRO Input: Specimen Geometry

<table>
<thead>
<tr>
<th>Crack ID</th>
<th>Width (in)</th>
<th>Thickness (in)</th>
<th>Crack Length, c (in)</th>
<th>Crack Depth, a (in)</th>
</tr>
</thead>
<tbody>
<tr>
<td>UNI 050 35 1</td>
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<td>0.0240</td>
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<tr>
<td>UNI 050 35 4</td>
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<td>0.0500</td>
<td>0.02050</td>
<td>0.0246</td>
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<tr>
<td>UNI 050 35 5</td>
<td>2.0000</td>
<td>0.0500</td>
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<td>0.0246</td>
</tr>
<tr>
<td>UNI 090 35 1</td>
<td>1.9600</td>
<td>0.0900</td>
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<tr>
<td>COPV 090 35 2</td>
<td>1.9700</td>
<td>0.0900</td>
<td>0.02100</td>
<td>0.0252</td>
</tr>
<tr>
<td>COPV 090 35 3</td>
<td>1.9800</td>
<td>0.0900</td>
<td>0.02000</td>
<td>0.0240</td>
</tr>
<tr>
<td>COPV 090 36 1</td>
<td>2.0250</td>
<td>0.0900</td>
<td>0.06000</td>
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<tr>
<td>COPV 090 36 2</td>
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<tr>
<td>MT 2</td>
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<td>2.9900</td>
<td>0.0870</td>
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</tr>
</tbody>
</table>
0.125” Uniaxial Test Data

Comparison of Test and Analytical Crack Growth
UNI-125-35-3

![Graph showing comparison of test and analytical crack growth with cycles on the x-axis and 2c (inch) on the y-axis. Different symbols and lines represent visual data and analytical data with different parameters.](image-url)
0.125” Fracture Surface

- 0.030 inch
- 0.049 inch
- 0.044 inch
- 0.092 inch

a/c = 1.07
a/c = 1.36
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

Pre-crack

Notch

a/c=1.1

0.067 in.

0.037 in.

0.026 in.

a/c=1.3

0.040 in.
Promising Analytical Result

0.05" Thick

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

- Visual
- NASGRO (a=.024)
- NASGRO (a=.026)

Cycles

2c (inches)
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