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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

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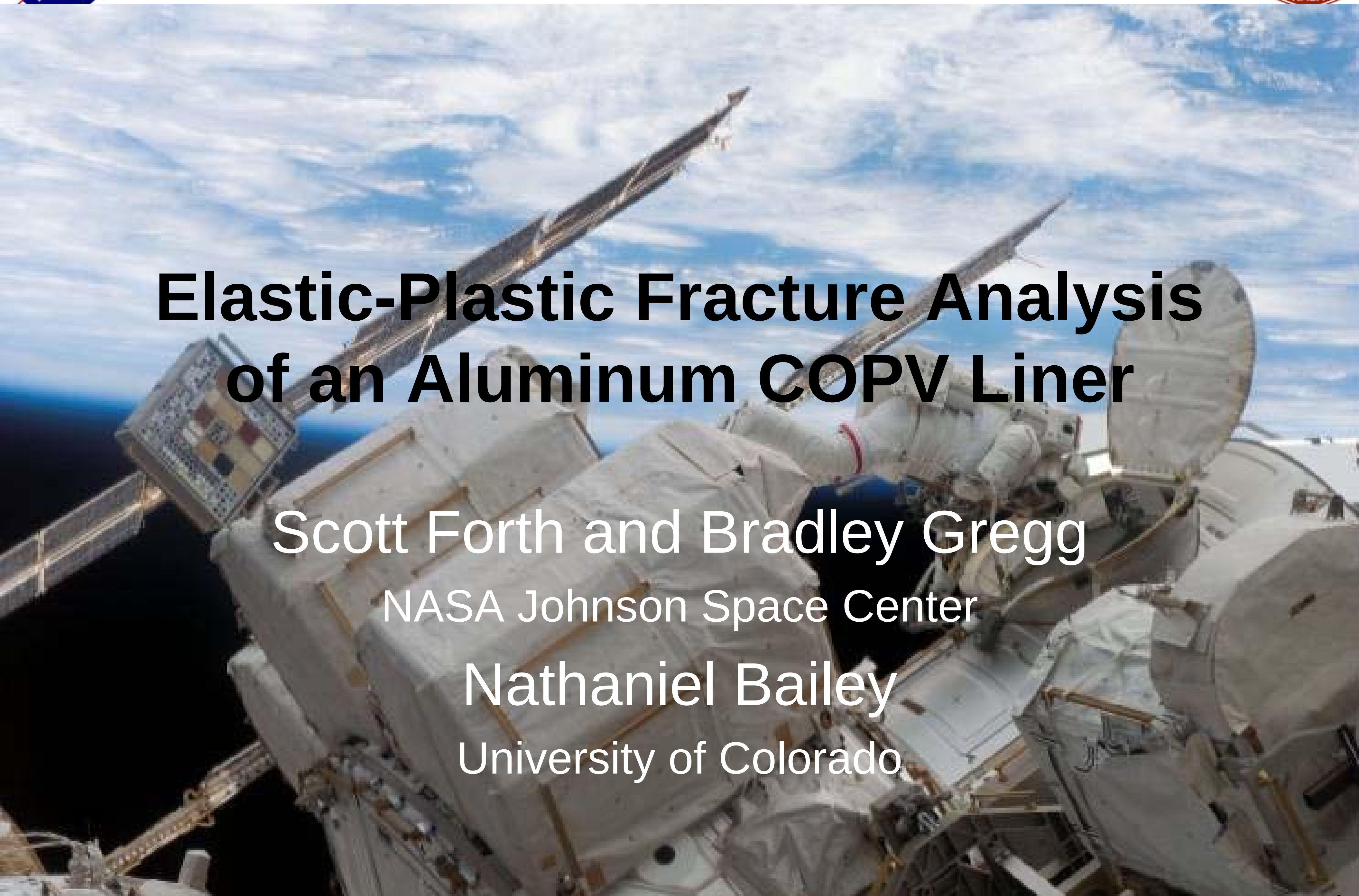

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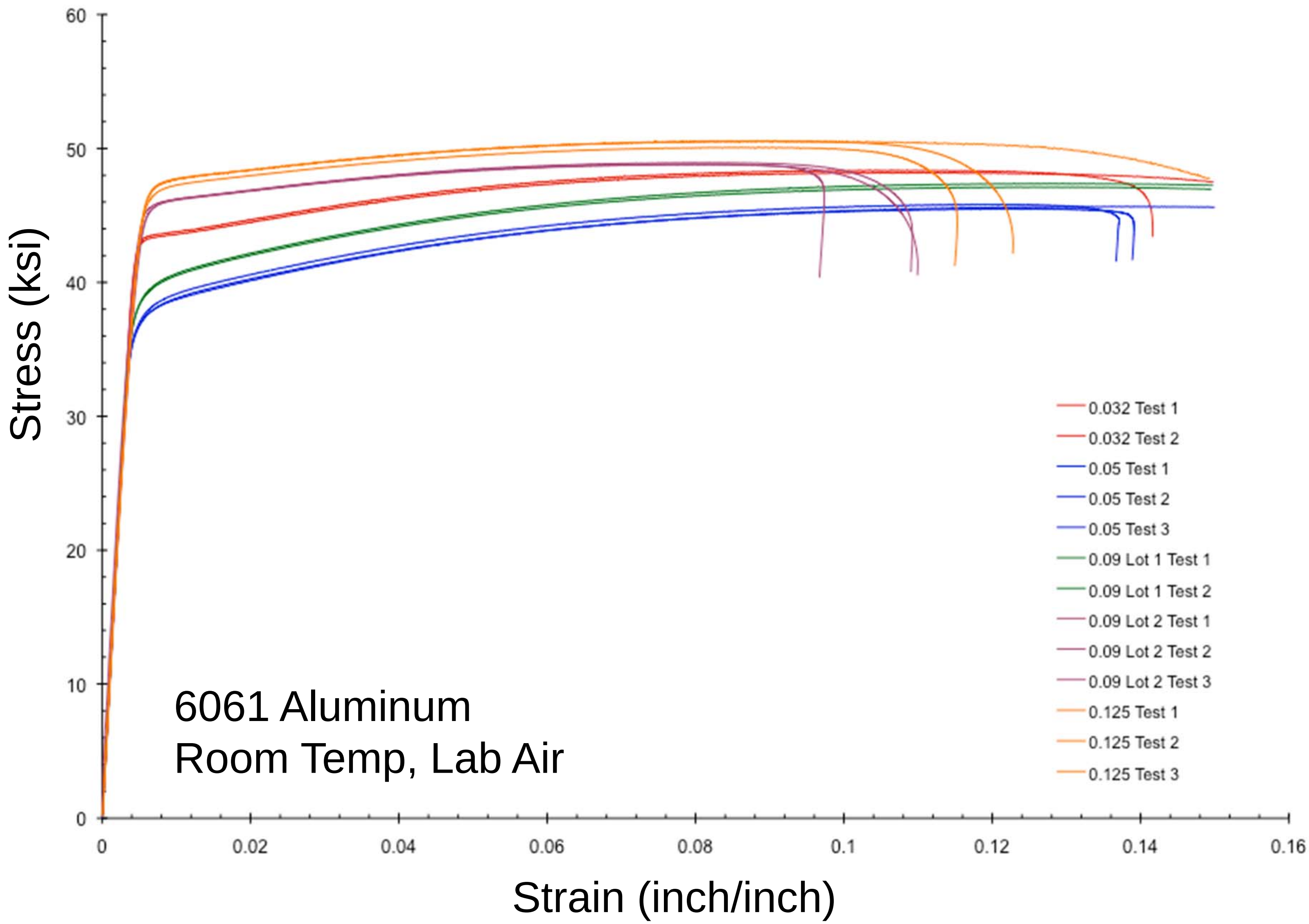
Aluminum Liner

- 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

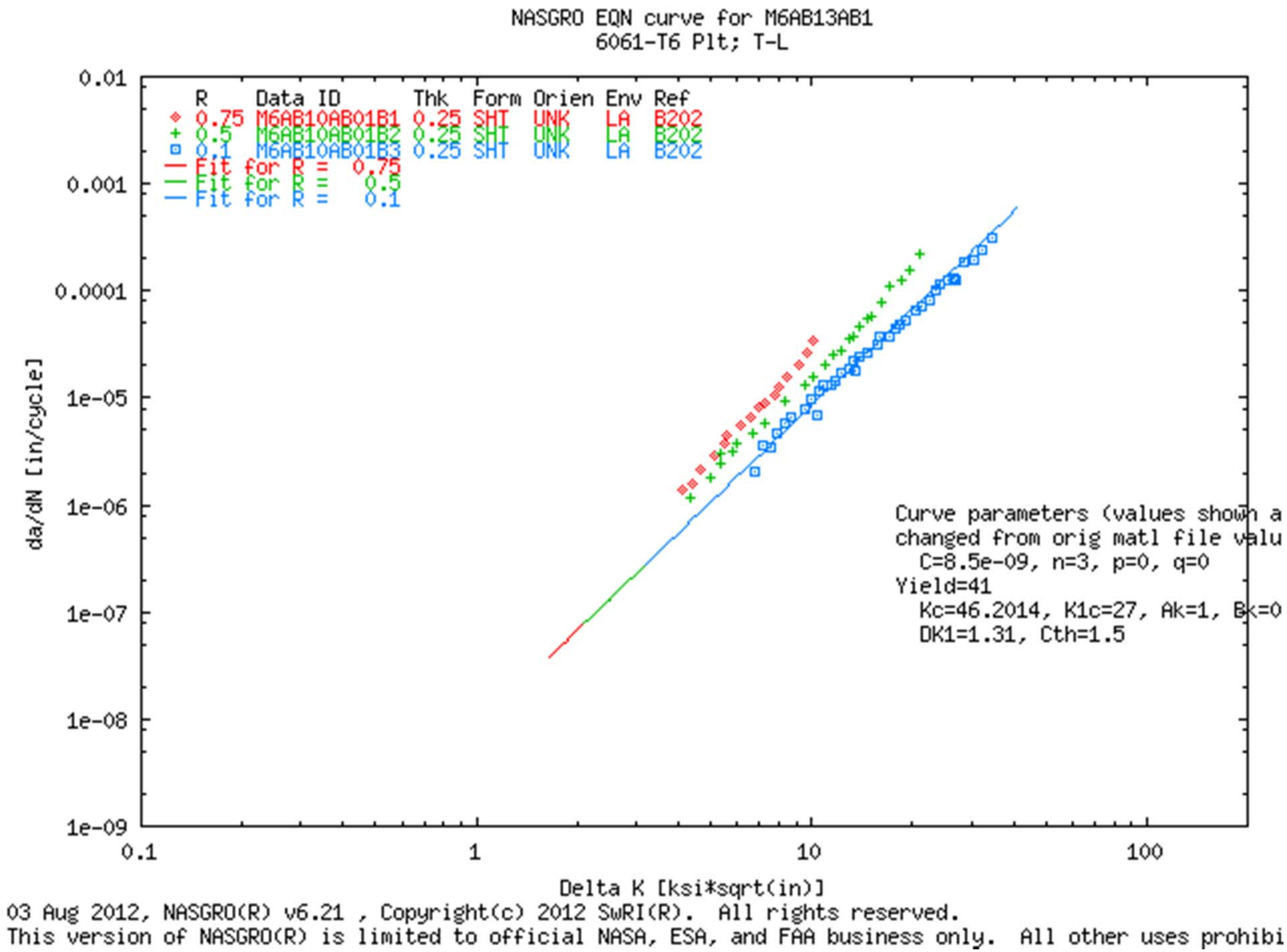
Stress Strain Response



Material Characterization

Thickness	Yield (ksi)	Ultimate (ksi)	Young's Modulus (Msi)	Alpha (R-O)	R-O Exponent
0.032	43.4	48.3	10.041	0.002	50
0.050	37.5	45.7	10.020	0.002	25
0.090 Lot 1 0.090 Lot 2	39.5 45.5	47.2 48.9	9.986 9.708	0.002 0.002	30 50
0.125	46.63	50.41	9.887	0.002	30

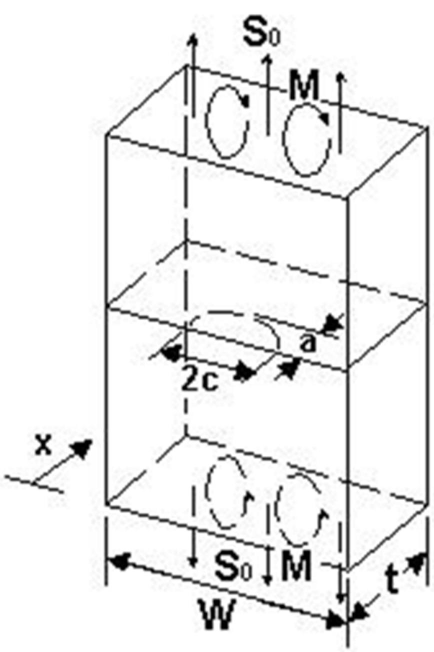
Crack Growth Rate



Elastic-Plastic Fracture Mechanics

- NASGRO 6.2 EPFM module

SC01



$$S_1 = \frac{6M}{Wt^2}$$

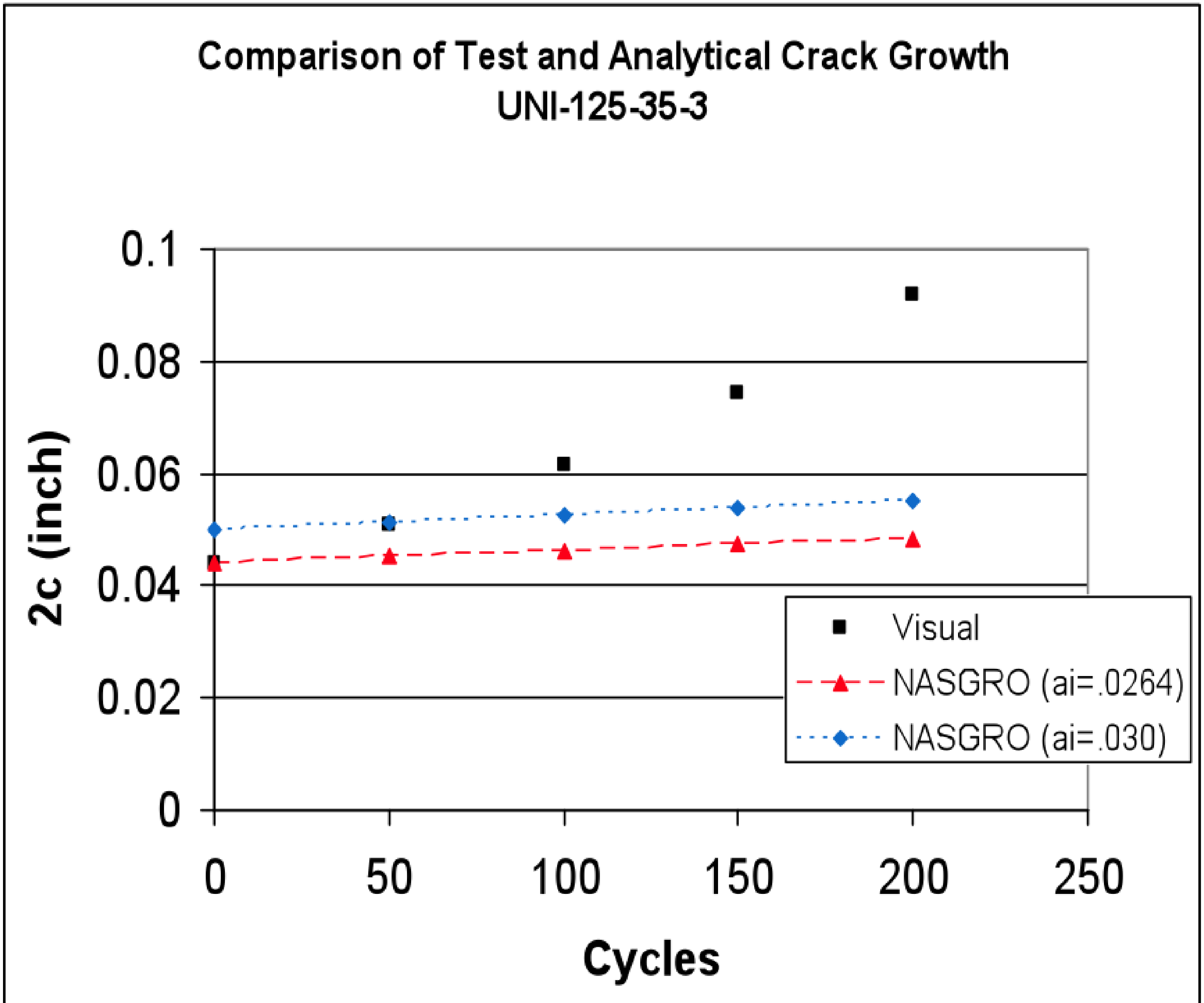
$$0 < \frac{2c}{W} \leq 1$$

$$0.1 \leq \frac{a}{c} \leq 1.2$$

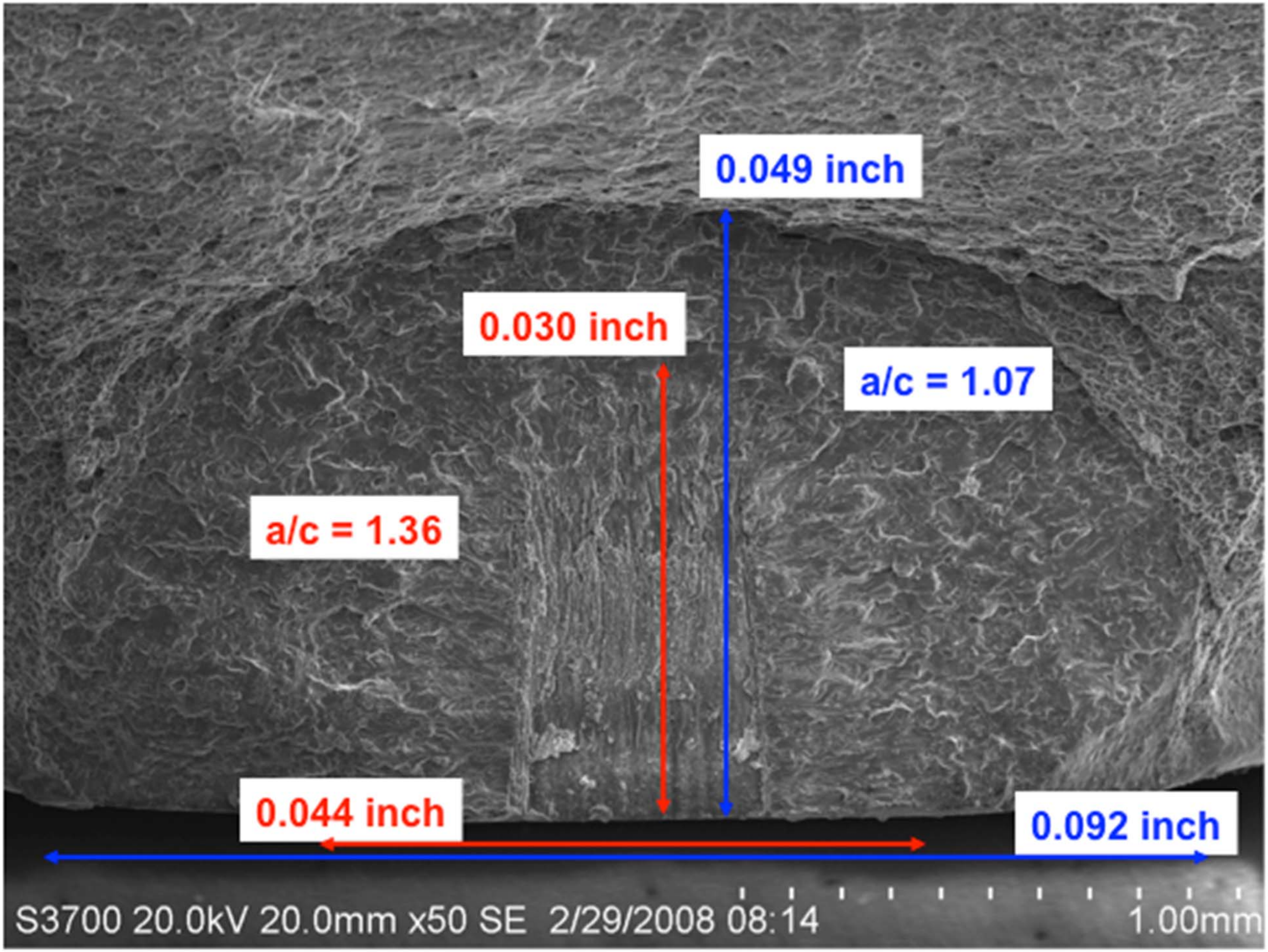
	Test Parameters			NASGRO Input		
Crack ID	Crack Length, c	Crack Depth, a	Crack Ratio, a/c	Crack Length, c	Crack Depth, a	Crack Ratio, a/c
UNI 050 35 1	0.0200	0.0260	1.3000	0.0200	0.0240	1.2000
UNI 050 35 4	0.0205	0.0280	1.3659	0.0205	0.0246	1.2000
UNI 050 35 5	0.0205	0.0260	1.2683	0.0205	0.0246	1.2000
UNI 090 35 1	0.0205	0.0340	1.6585	0.0205	0.0246	1.2000
COPV 090 35 2	0.0210	0.0350	1.6667	0.0210	0.0252	1.2000
COPV 090 35 3	0.0200	0.0340	1.7000	0.0200	0.0240	1.2000
COPV 090 36 1	0.0500	0.0120	0.2400	0.0500	0.0120	0.2400
COPV 090 36 2	0.0520	0.0200	0.3846	0.0520	0.0200	0.3846
COPV 090 36 4	0.0525	0.0200	0.3810	0.0525	0.5000	0.3800
UNI 125 35 1	0.0205	0.0340	1.6585	0.0205	0.0246	1.2000
UNI 125 35 2	0.0210	0.0310	1.4762	0.0210	0.0252	1.2000
UNI 125 35 3	0.0220	0.0300	1.3636	0.0220	0.0264	1.2000

NASGRO Input: Specimen Geometry				
Crack ID	Width (in)	Thickness (in)	Crack Length, c (in)	Crack Depth, a (in)
UNI 050 35 1	2.0000	0.0500	0.02000	0.0240
UNI 050 35 4	1.9950	0.0500	0.02050	0.0246
UNI 050 35 5	2.0000	0.0500	0.02050	0.0246
UNI 090 35 1	1.9600	0.0900	0.02050	0.0246
COPV 090 35 2	1.9700	0.0900	0.02100	0.0252
COPV 090 35 3	1.9800	0.0900	0.02000	0.0240
COPV 090 36 1	2.0250	0.0900	0.05000	0.0600
COPV 090 36 2	2.0000	0.0900	0.05200	0.0624
COPV 090 36 4	2.0000	0.0900	0.05250	0.0630
UNI 125 35 1	1.9400	0.1250	0.02050	0.0246
UNI 125 35 2	2.0200	0.1250	0.02100	0.0252
UNI 125 35 3	1.9850	0.1250	0.02200	0.0264
MT 1	3.0300	0.0900	0.24025	0.0900
MT 2	3.0300	0.0900	0.24175	0.0900
MT 3	2.9900	0.0870	0.27600	0.0870

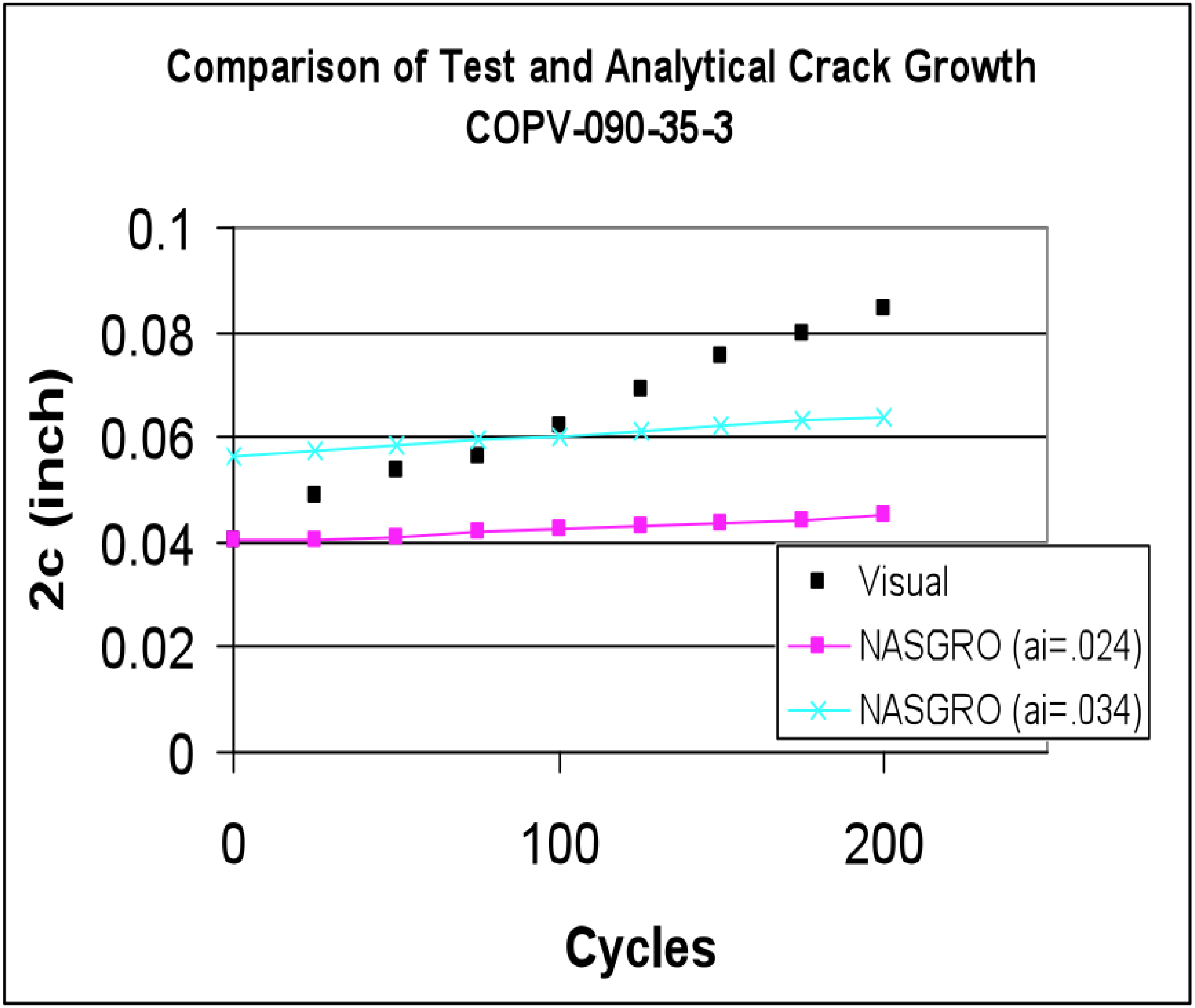
0.125” Uniaxial Test Data



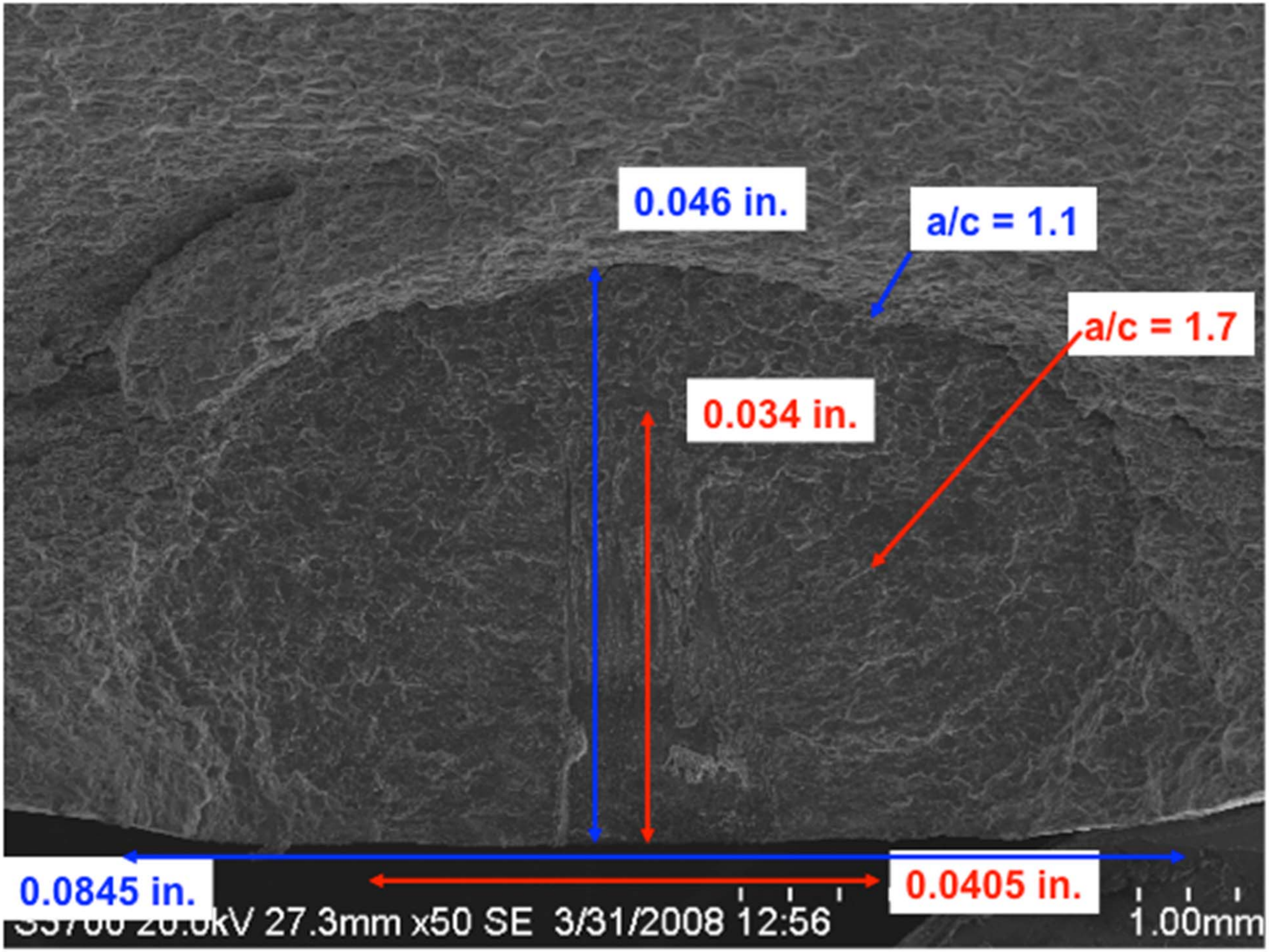
0.125” Fracture Surface



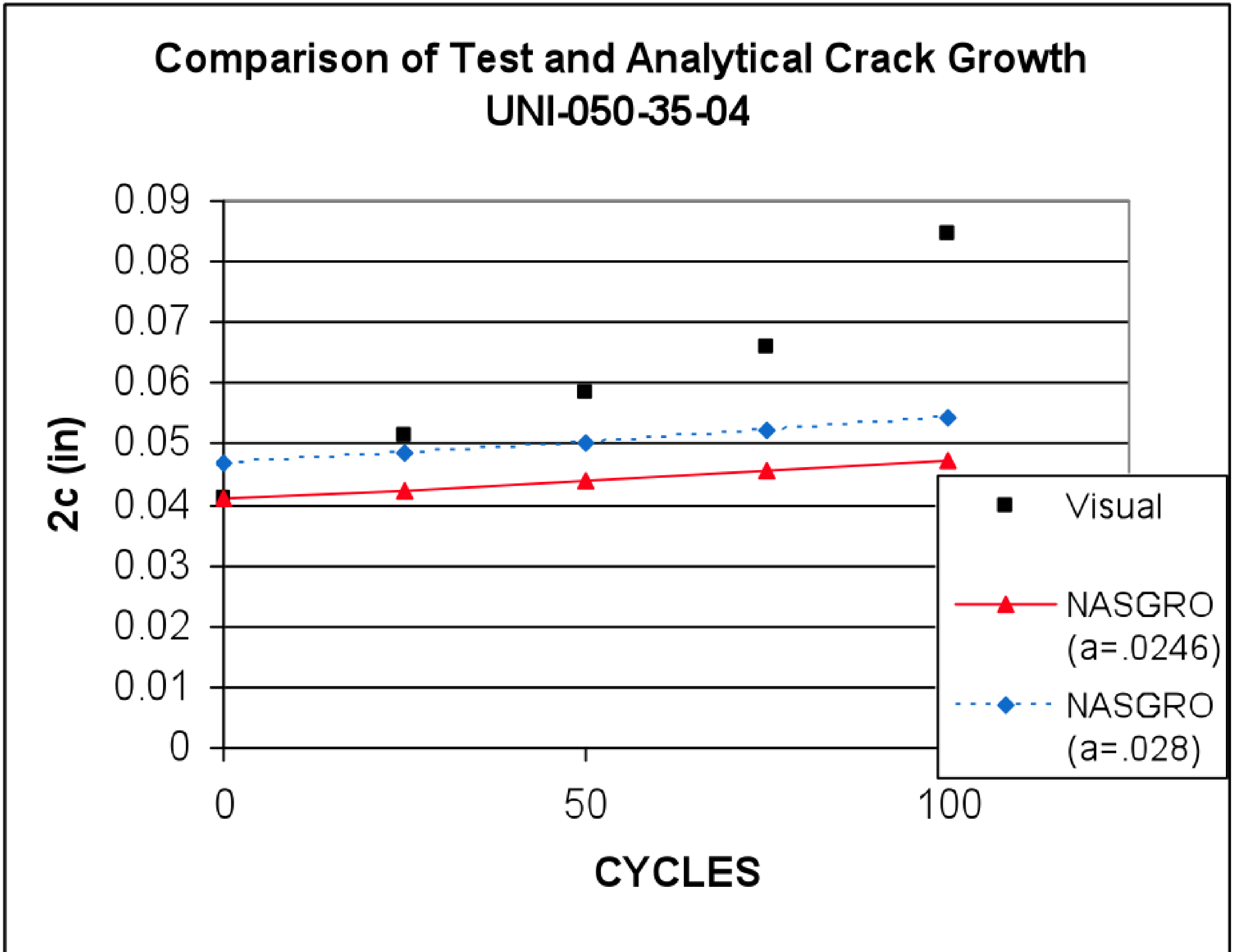
0.090" Uniaxial Test Data



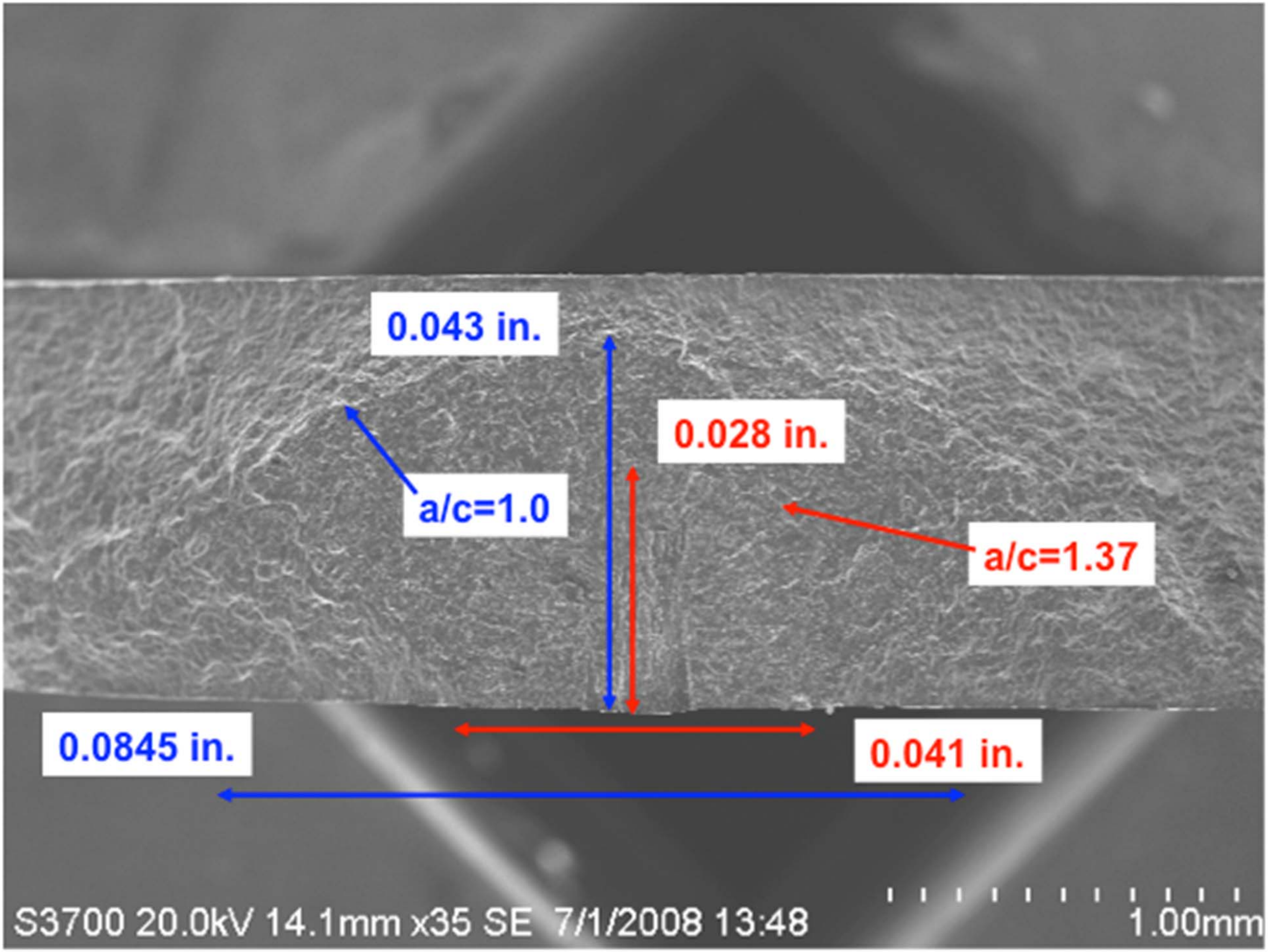
0.090” Fracture Surface



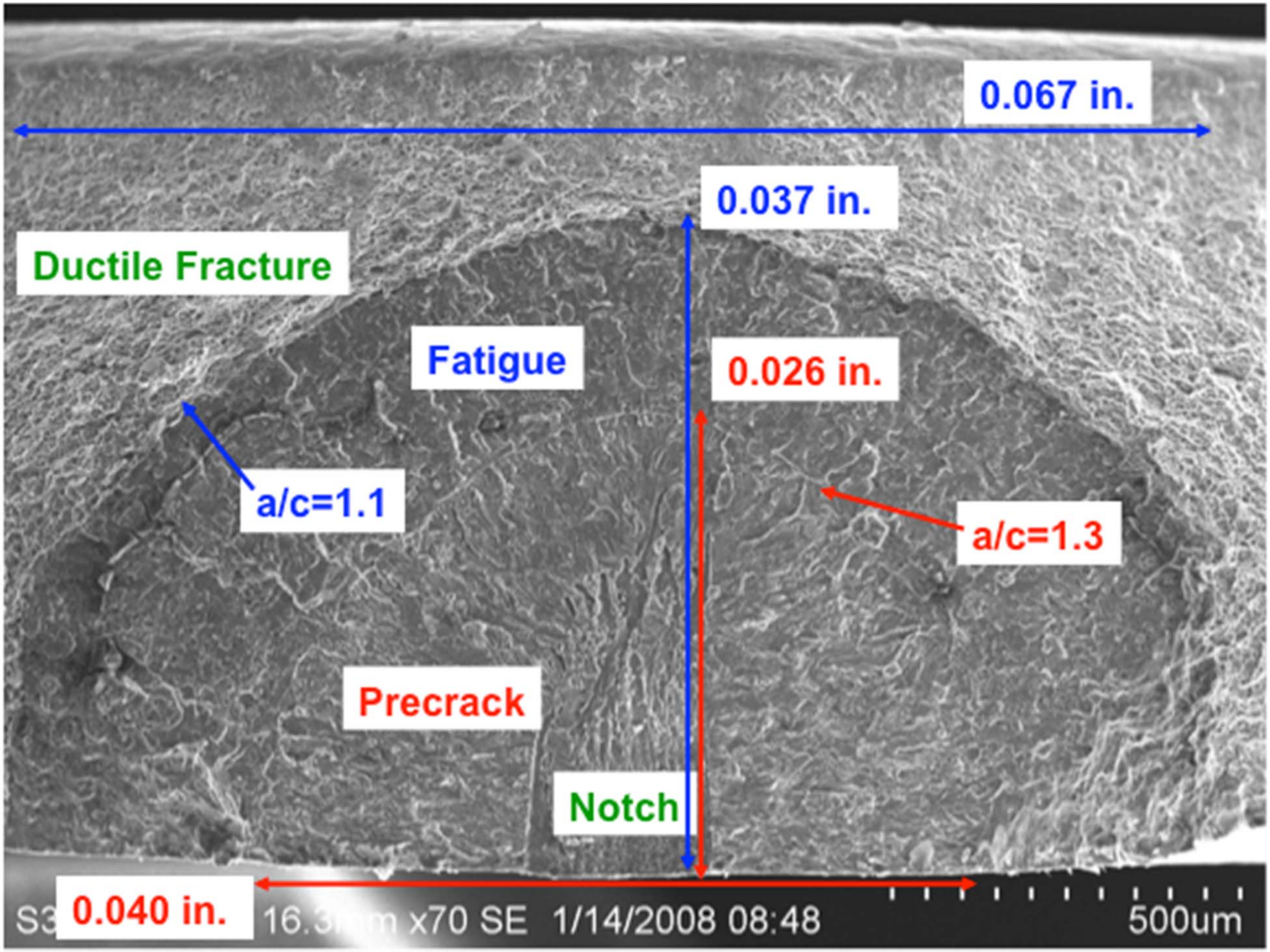
0.050” Uniaxial Test Data



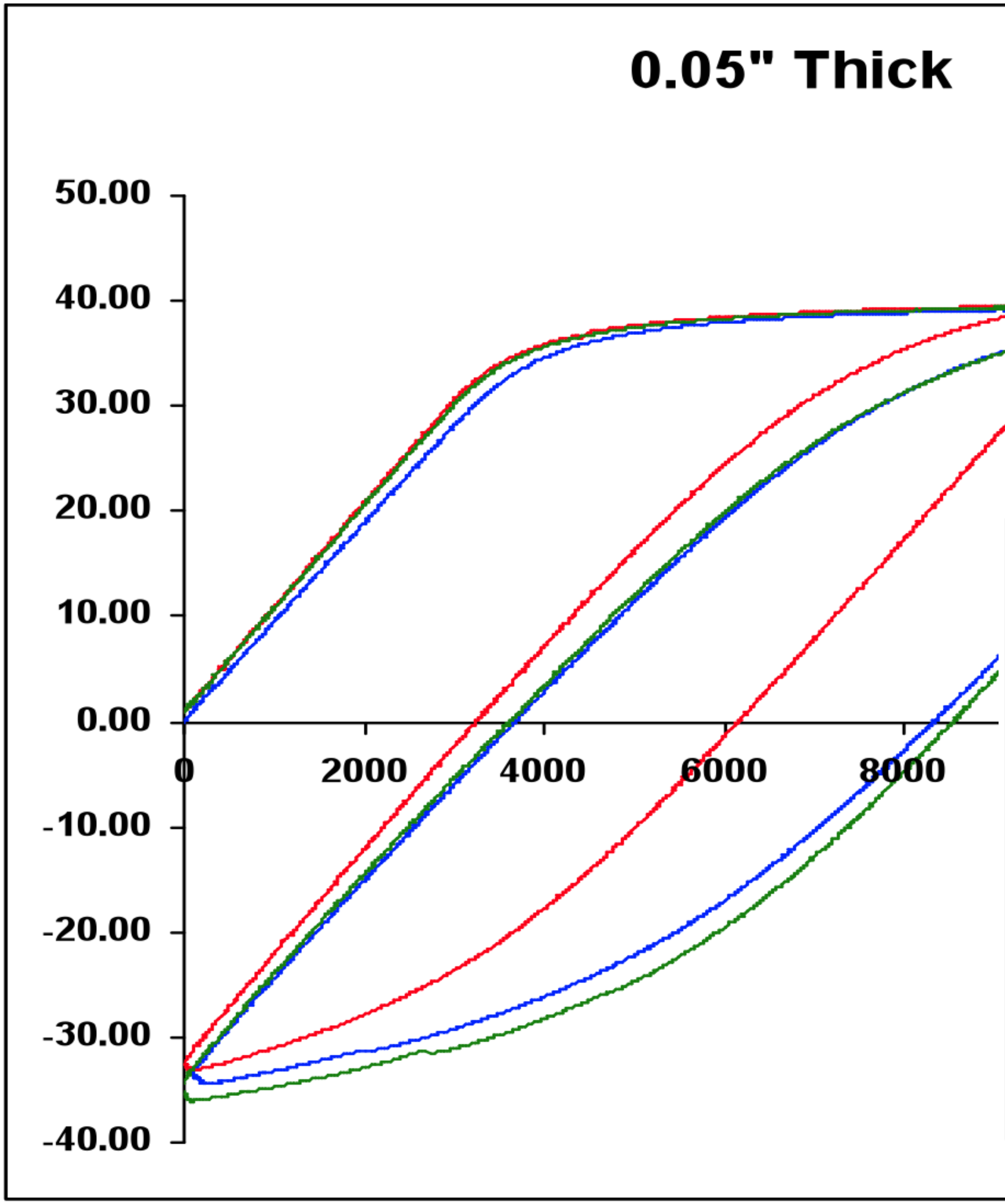
0.050” Fracture Surface

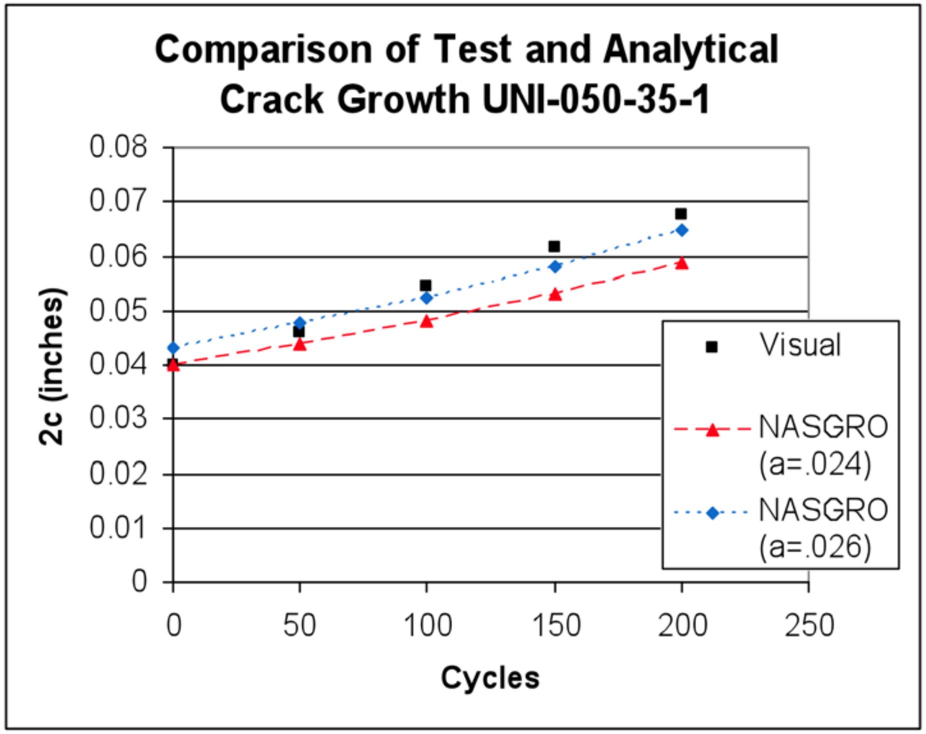


Token Promising Result



Promising Analytical Result





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