2007 Aircraft Structural Integrity Program Conference

The Effect of Stress Intensity Factor Models on Inspection Intervals

U.S. AIR FORCE

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Integrity - Service - Excellence

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Outline

- *K* Solutions
  - Geometric & Loading Parameter Space
  - Verification
  - Validation
- Fatigue Life Predictions Using New *K* Solutions
  - Fatigue Life
  - Continuing Damage Scenario
    - Phase I Life
    - Crack Size
  - Effect of r/t
- Conclusions

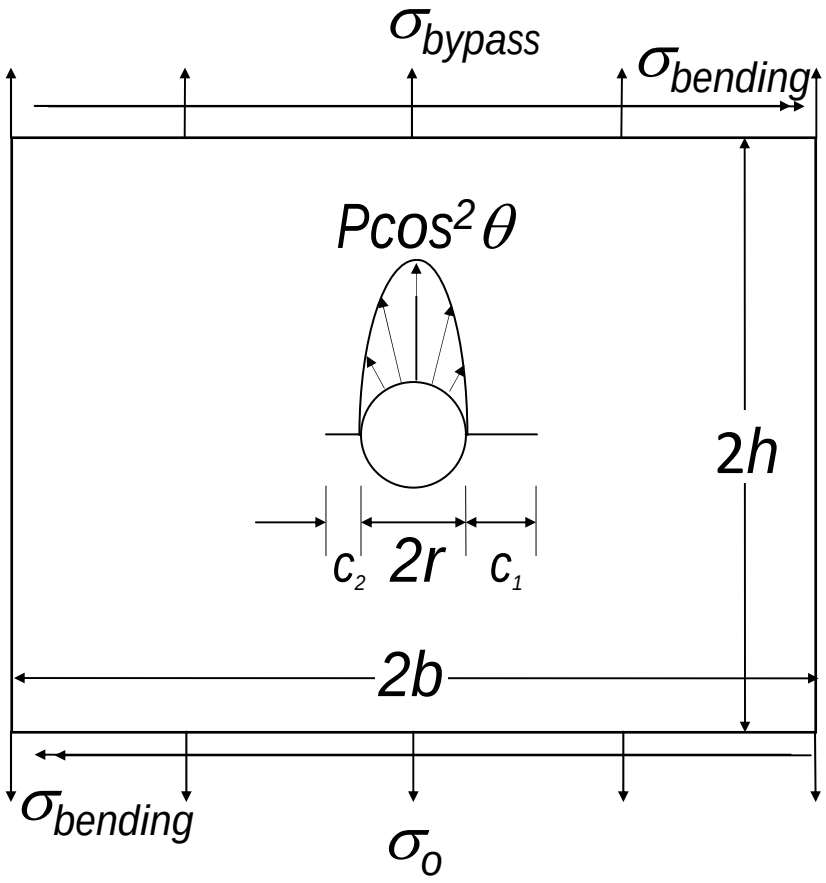
Small differences in *K* Solutions yield large cumulative differences in fatigue life

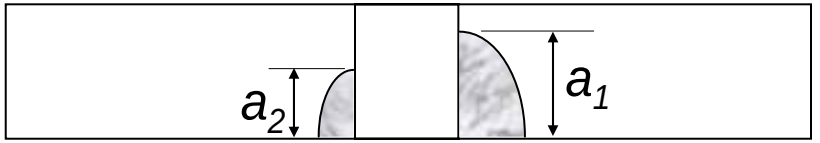
…and large differences in K solutions yield even a larger cumulative difference in fatigue life

Parameter Space

K-Solutions, ≈ 1.0 million CPU Hours

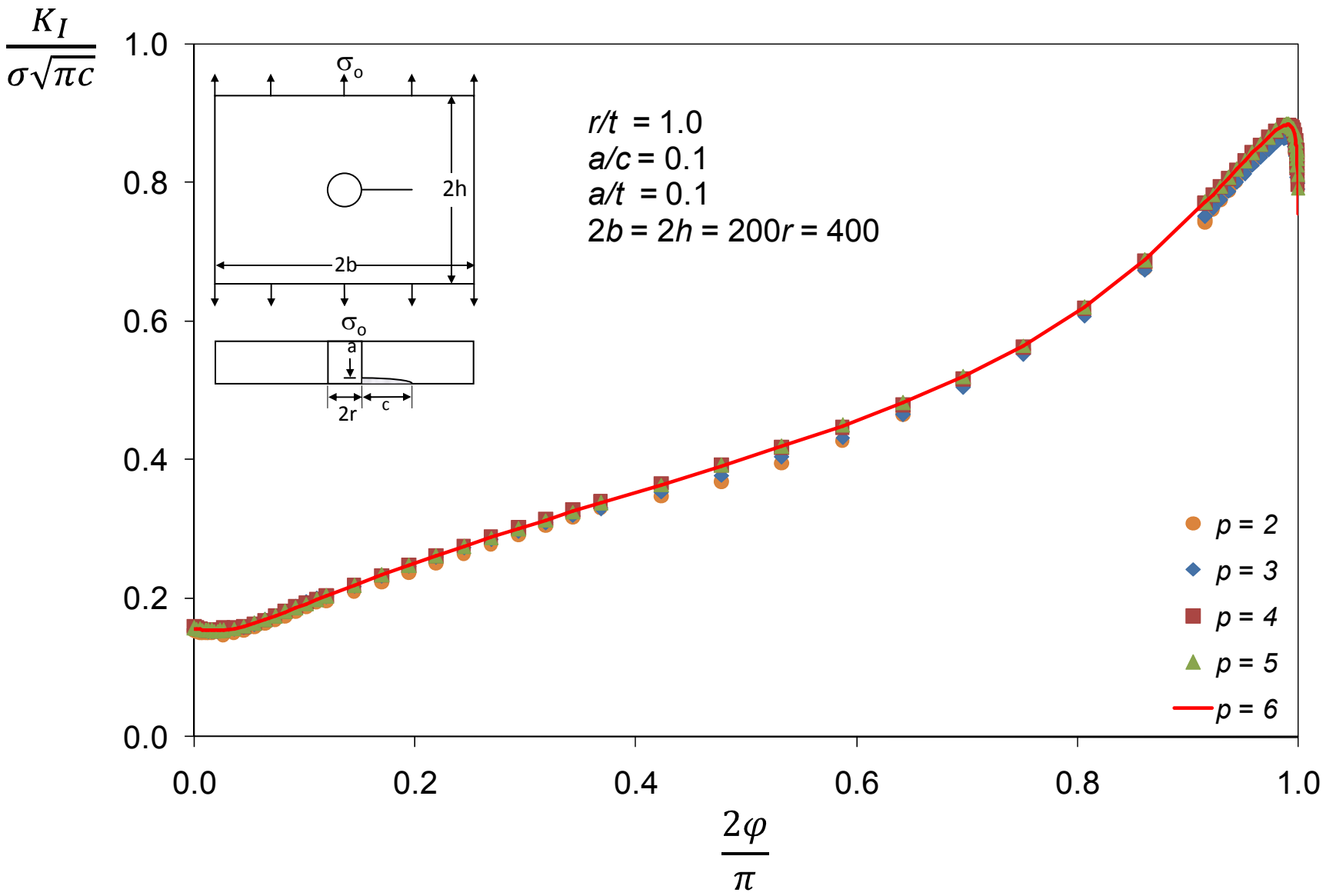
- Geometry
  - Centrally Located Straight Shank Hole
  - $0.1 \leq r/t \leq 10.0$
    - 0.1, 0.111, 0.125, 0.1428, 0.1667, 0.2, 0.25, 0.333, 0.5, 0.667, 0.75, 0.8, 1.0, 1.25, 1.333, 1.5, 1.667 2.0, 3.0, 4.0, 5.0, 6.0, 7.0, 8.0, 9.0, 10.0 **(r/t = 0.5, 1.0)**
  - Finite Width/Height Plate
    - r/h = 0.0025
    - r/b = 0.0025
- Crack Shapes
  - $0.1 \leq a/c \leq 10.0$
    - 0.1, 0.111, 0.125, 0.1428, 0.1667, 0.2, 0.25, 0.333, 0.5, 0.667, 0.75, 0.8, 1.0, 1.25, 1.333, 1.5, 2.0, 3.0, 4.0, 5.0, 6.0, 7.0, 8.0, 9.0, 10.0 **(a/c = 0.2, 0.5, 0.8, 1.0, 2.0)**
  - $0.1 \leq a/t \leq 0.99$
    - 0.1, 0.2, 0.3, 0.4, 0.5, 0.6, 0.7, 0.8, 0.9, 0.95, 0.99 **(a/t = 0.2, 0.5, 0.8)**
- Load Conditions
  - Tension
  - Bending
  - Pin Loading (Bearing)
- *5,672,700* solutions



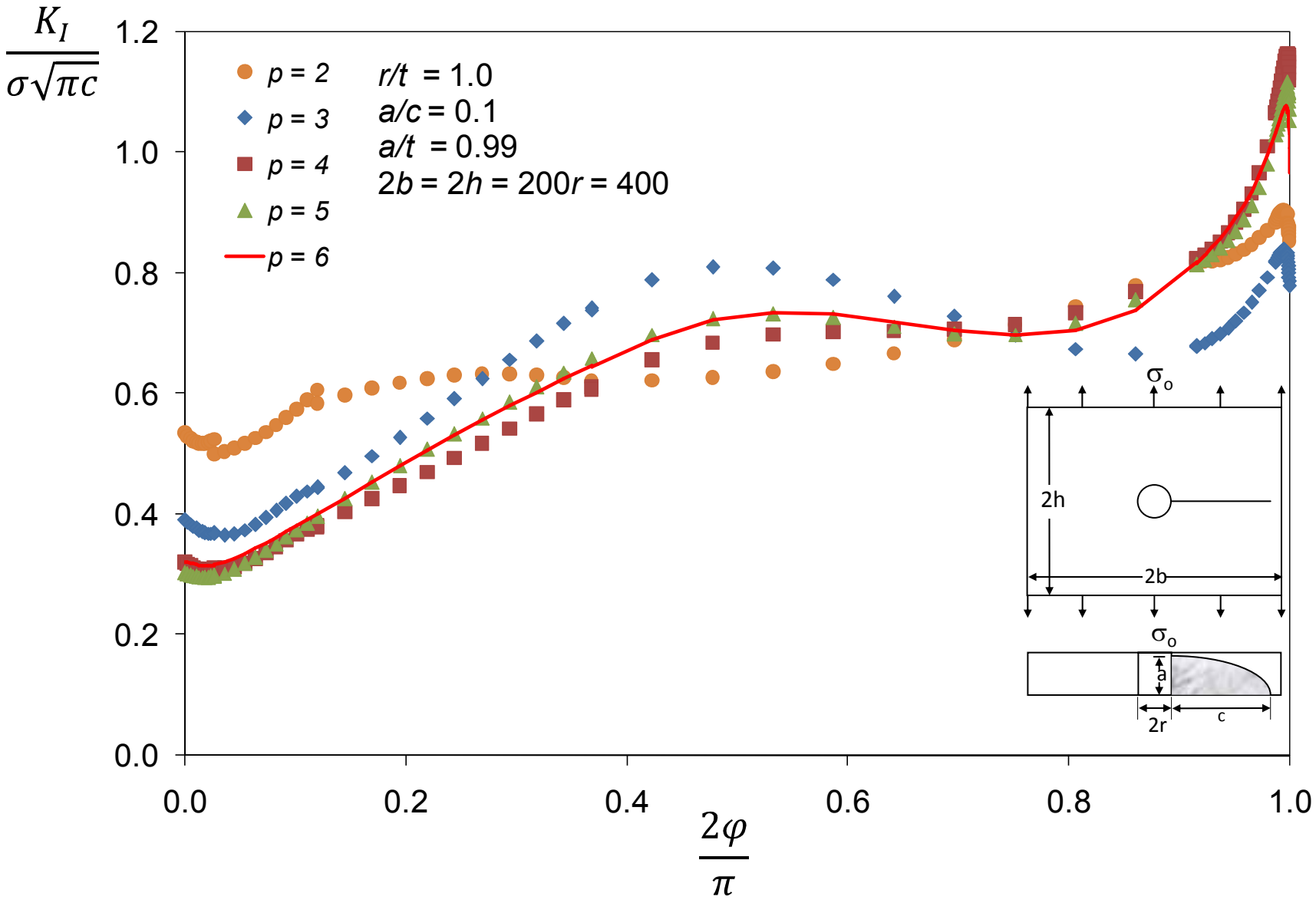


K-Solution Verification

Convergence: Shallow Crack

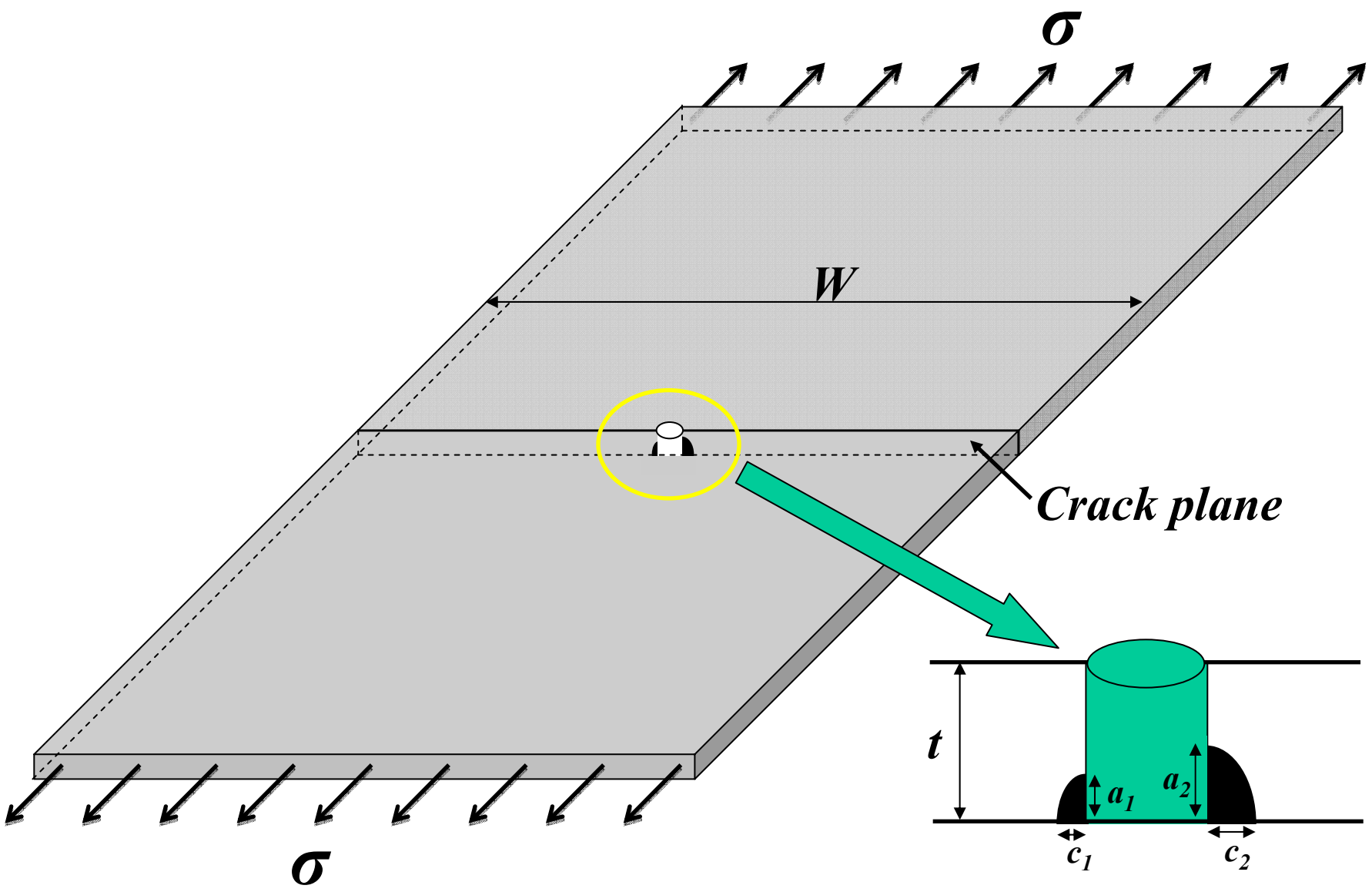


Convergence: Deep Crack

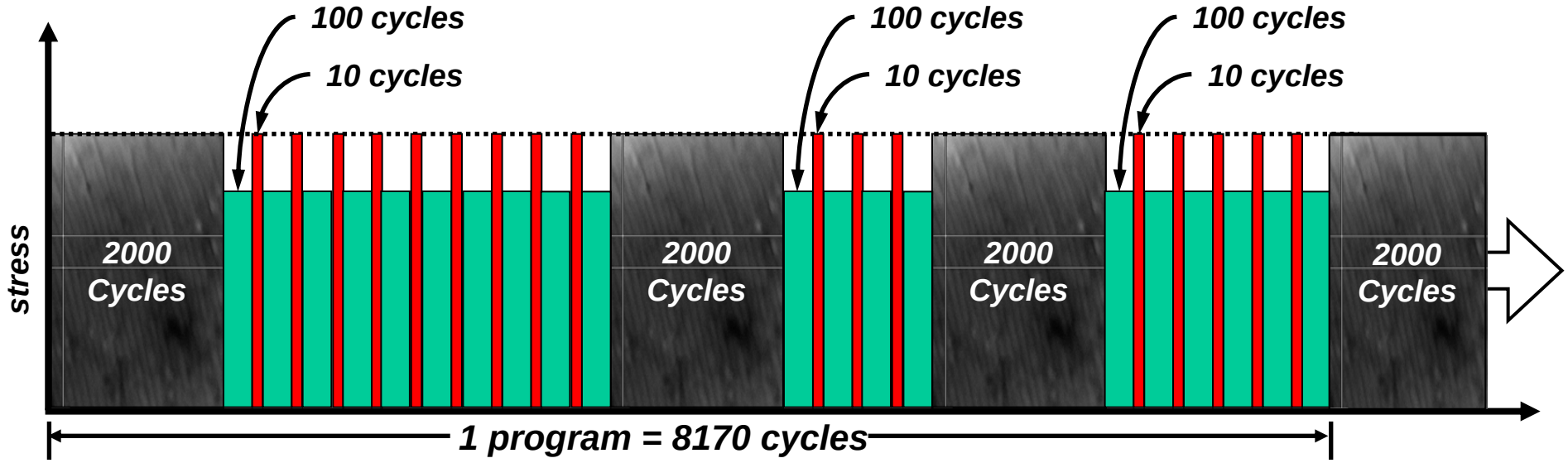


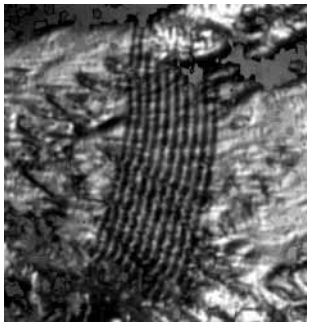
K-Solution Validation

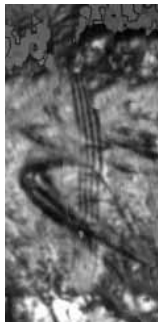
Test Specimen Configuration

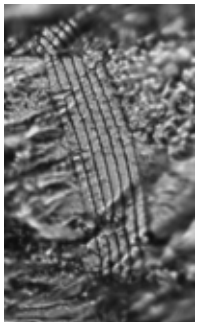


Marker Load Spectrum

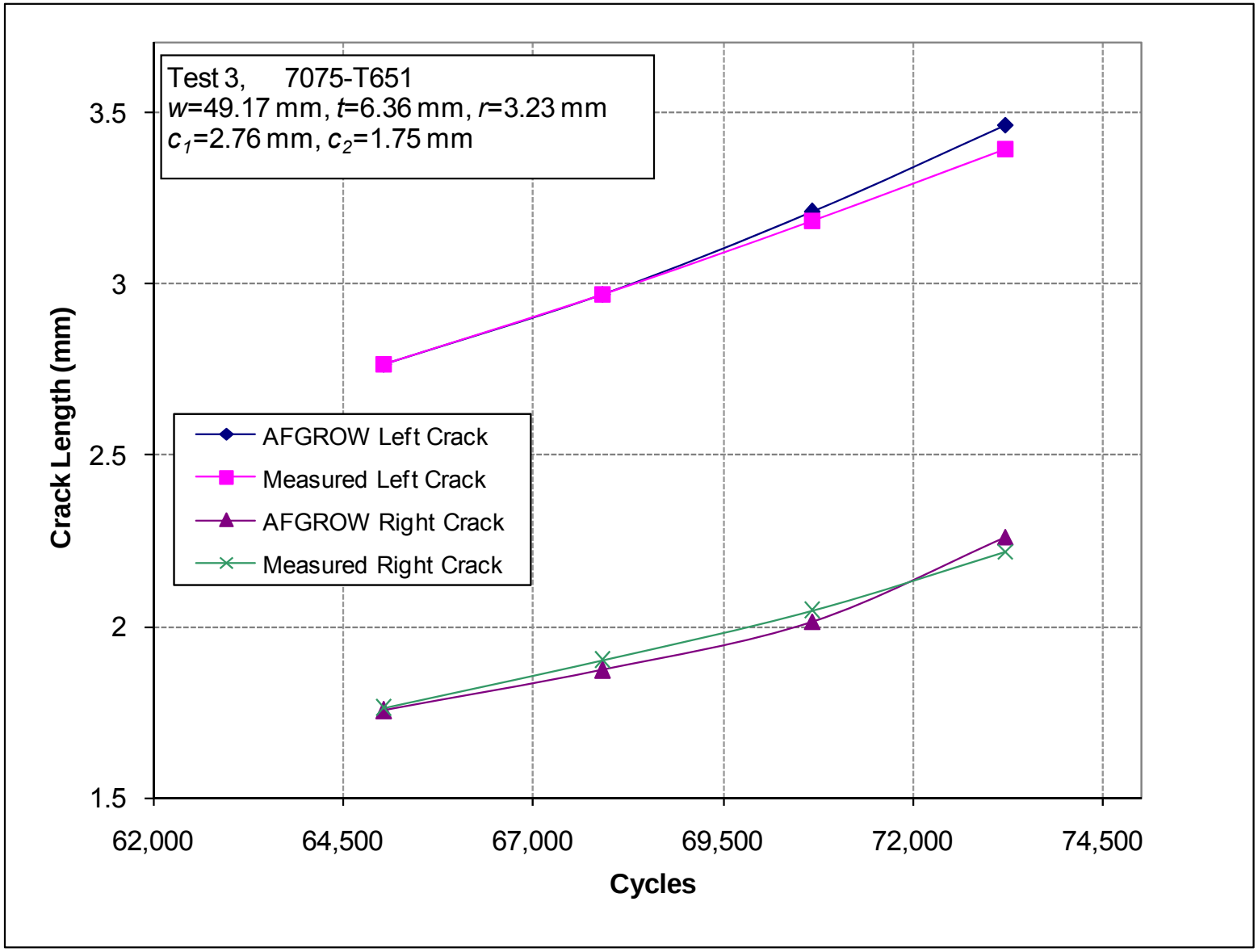




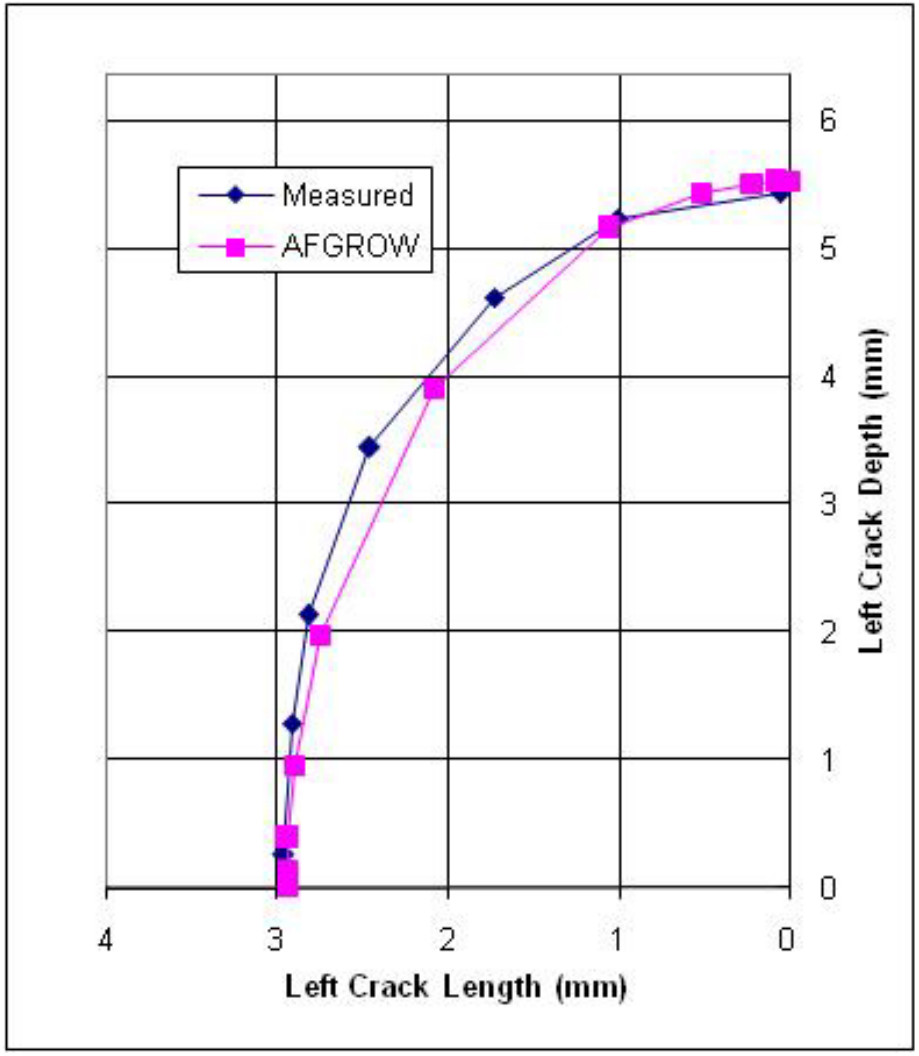


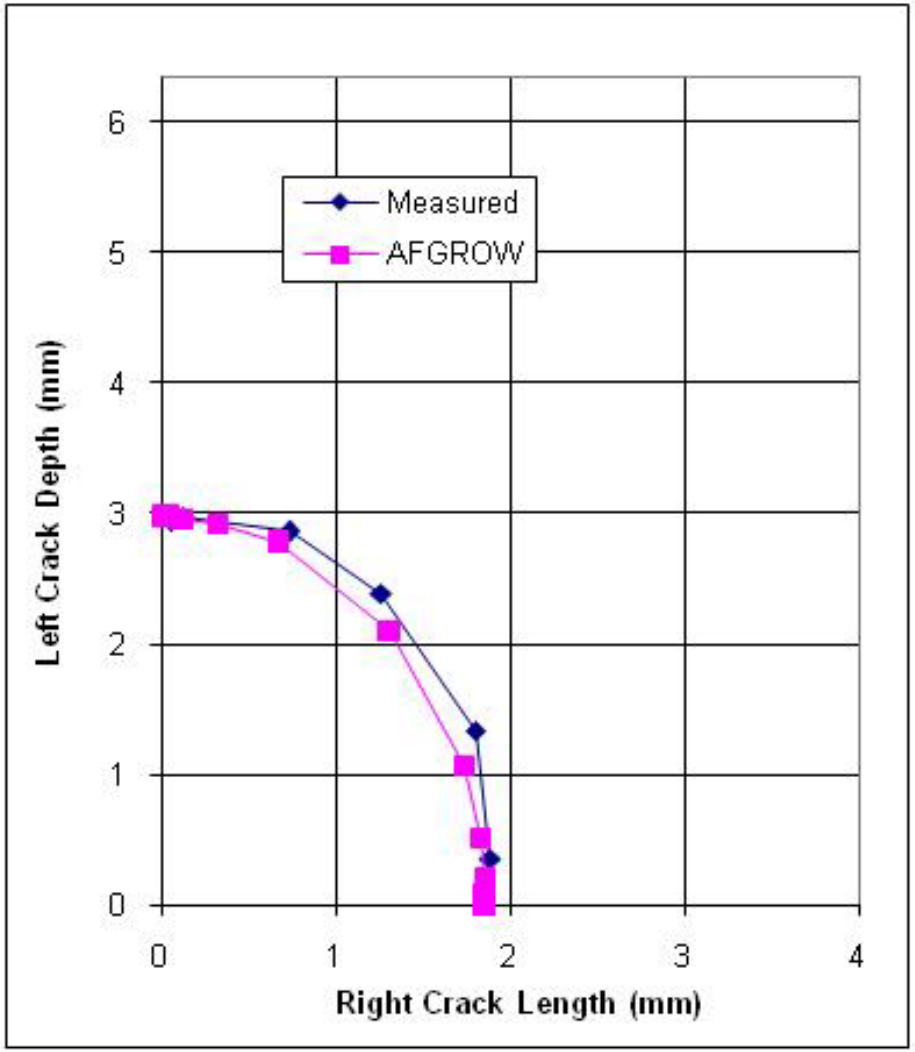


Fatigue Life Prediction

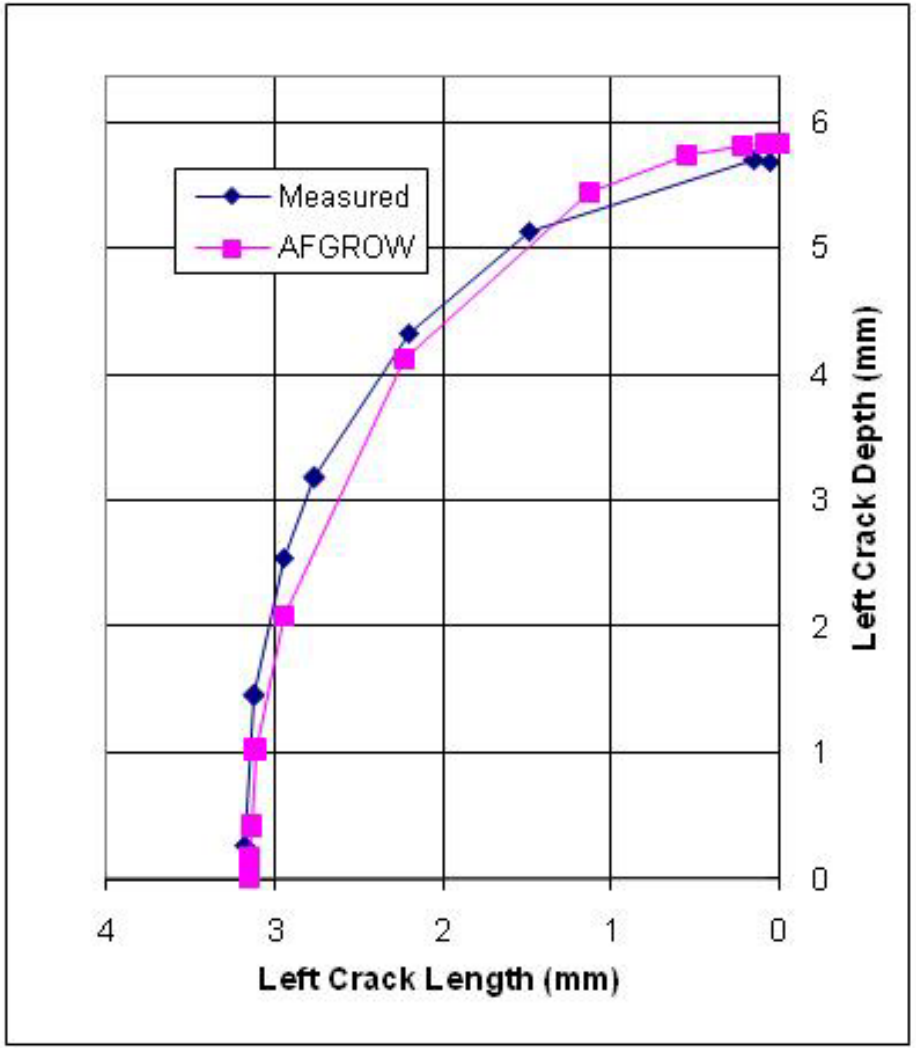


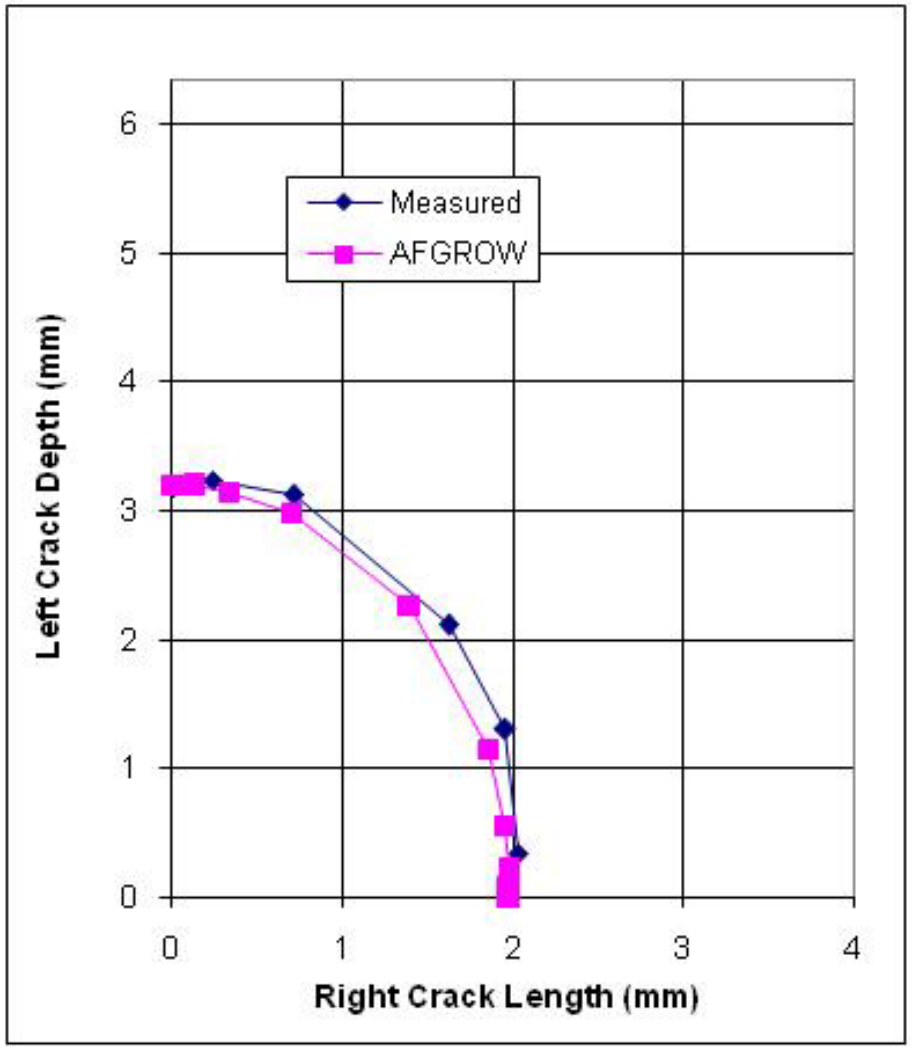
Crack Shape Development



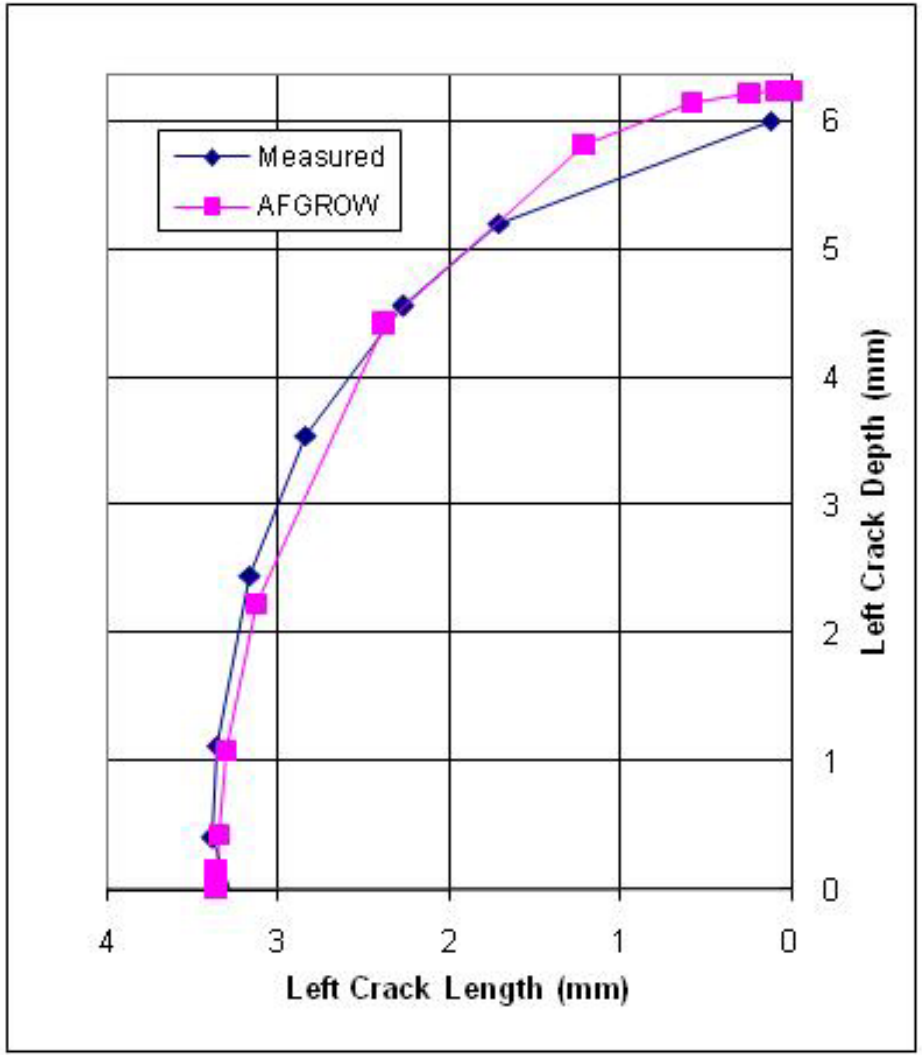


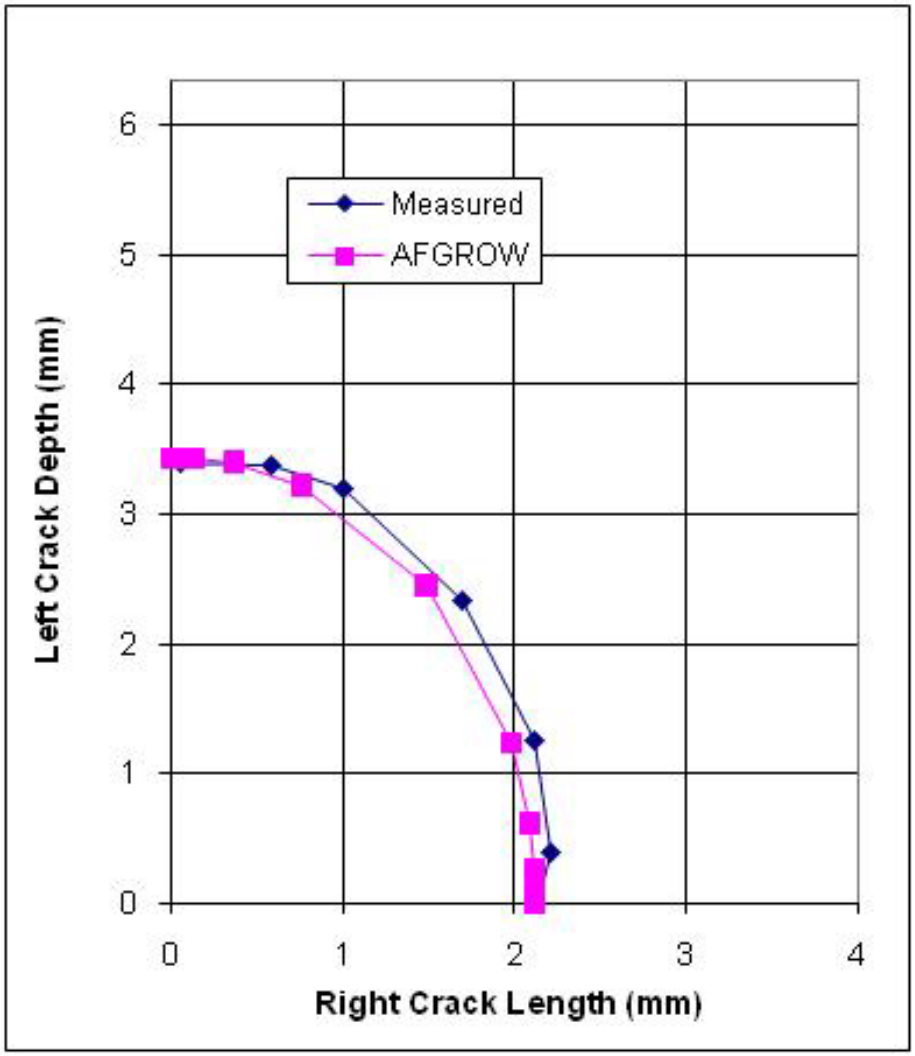
Crack Shape Development





Crack Shape Development





Fatigue Life Predictions Using New *K* Solutions

Geometry for Assessing Effect on Life

Small Crack – Thin Sheet

W = 1.14 in, t = 0.063 in, D = 3/16 in

a_i = 0.01 in, c_i = 0.01 in, a_i/t = 0.2

a_i/c_i = 1.0, r/t = 1.5

TSR = 1.0, BSR = 0.4

Small Crack – Thick Sheet

W = 4.53 in, t = 0.25 in, D = ¾ in

a_i = 0.05 in, c_i = 0.05 in, a_i/t = 0.2

a_i/c_i = 1.0, r/t = 1.5

TSR = 1.0, BSR = 0.4

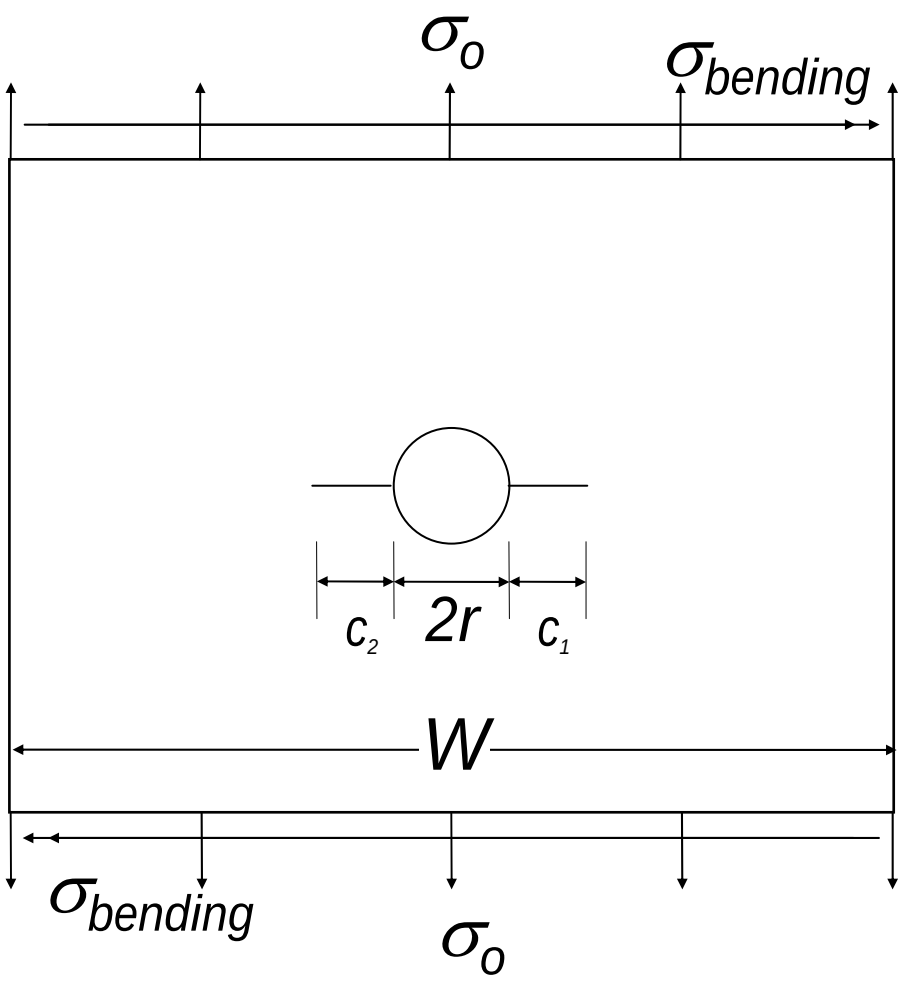
Large Crack – Thin Sheet

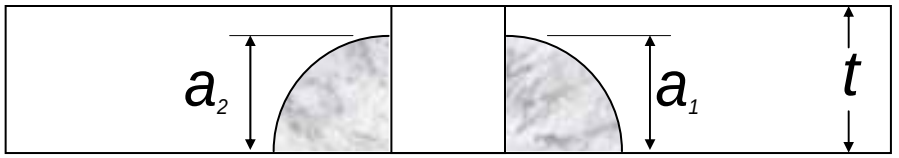
W = 1.14 in, t = 0.063 in, D = 3/16 in

a_i = 0.05 in, c_i = 0.05 in, a_i/t = 0.8

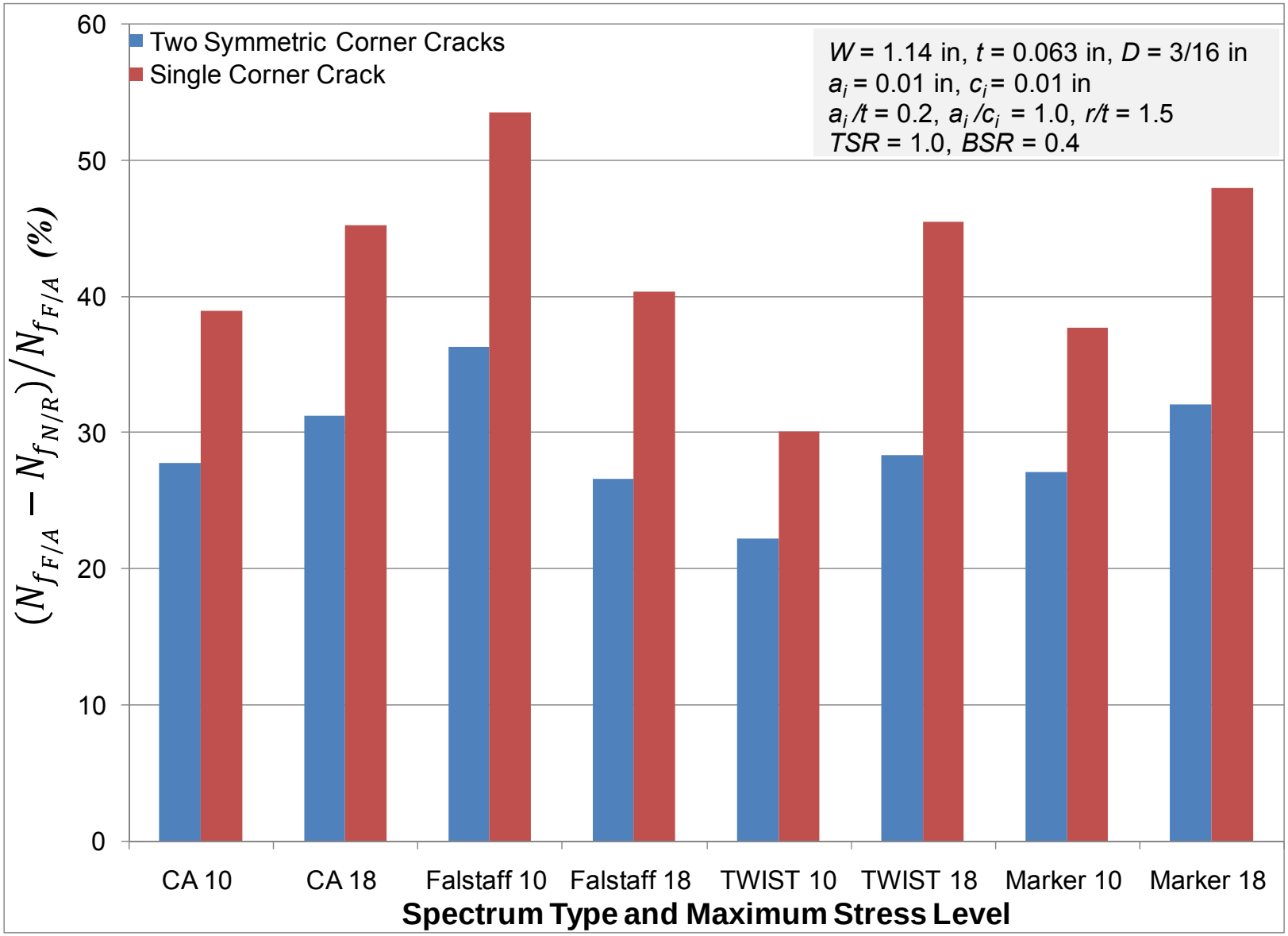
a_i/c_i = 1.0, r/t = 1.5

TSR = 1.0, BSR = 0.4

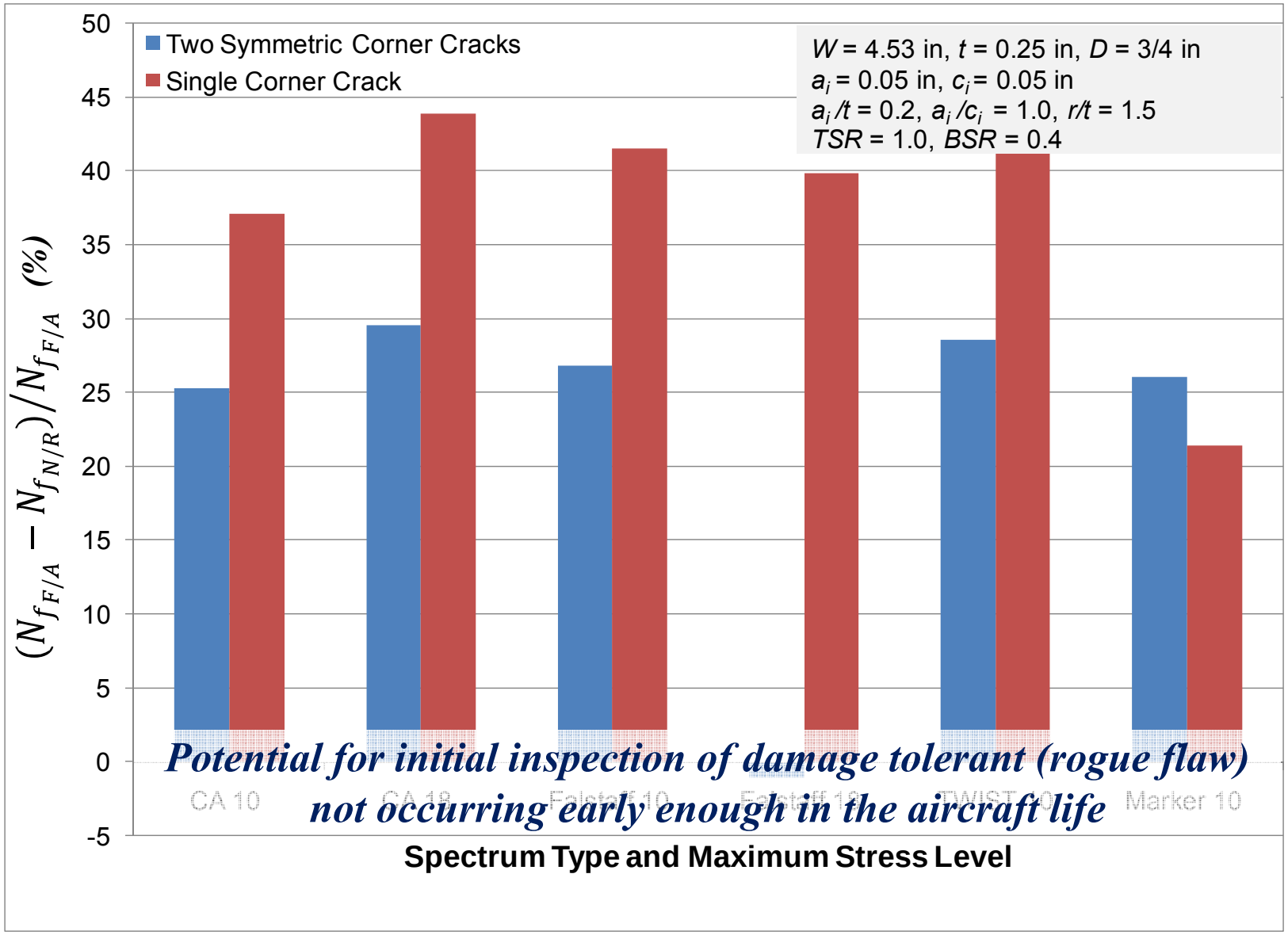




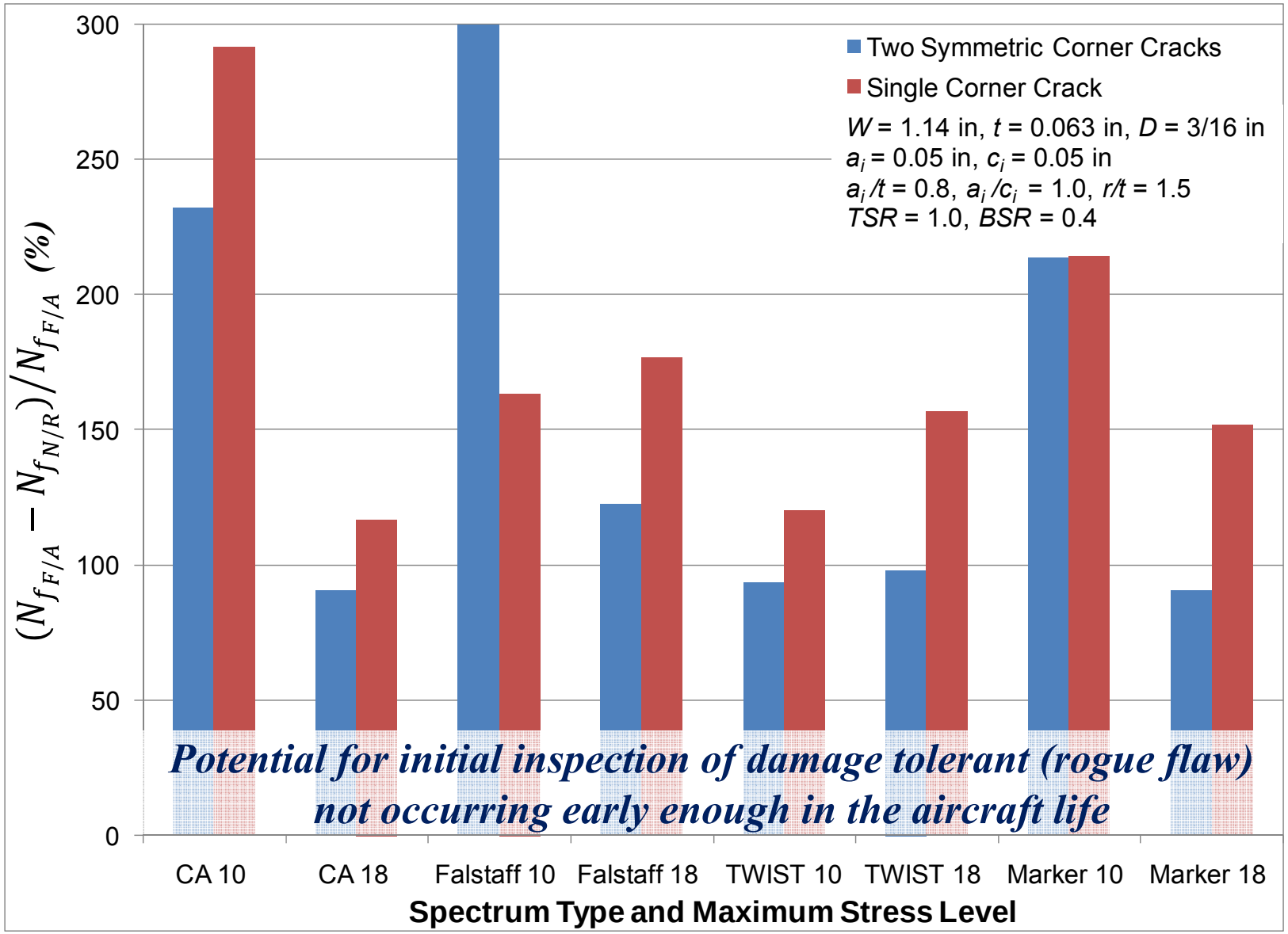
Effect on Life – Small Crack, Thin Sheet



Effect on Life – Small Crack, Thick Sheet



Effect on Life – Large Crack, Thin Sheet



Geometry for Assessing Effect on Continuing Damage Scenario

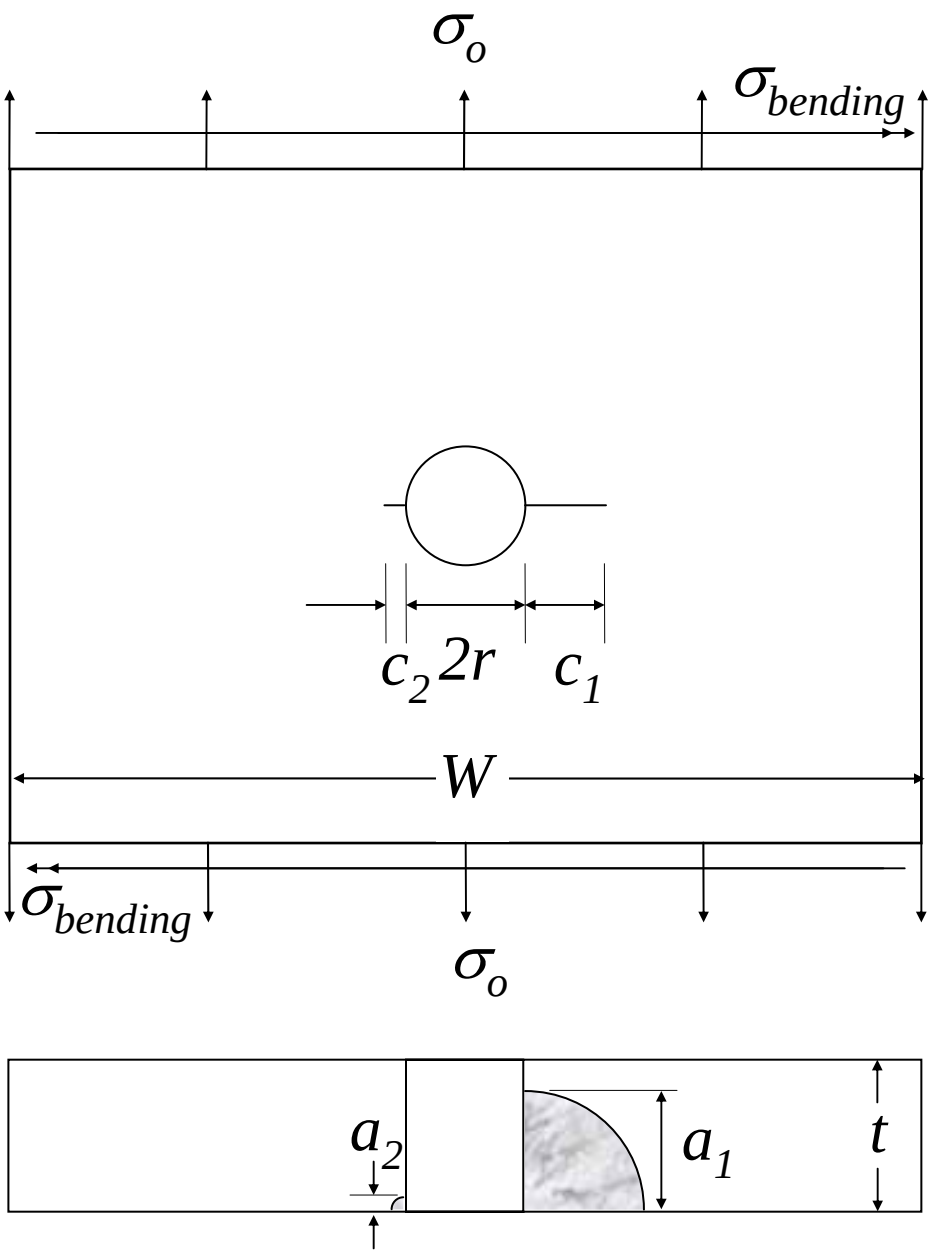
W = 1.14 in, t = 0.063 in, D = 3/16 in

a_1 = 0.05 in, c_1 = 0.05 in

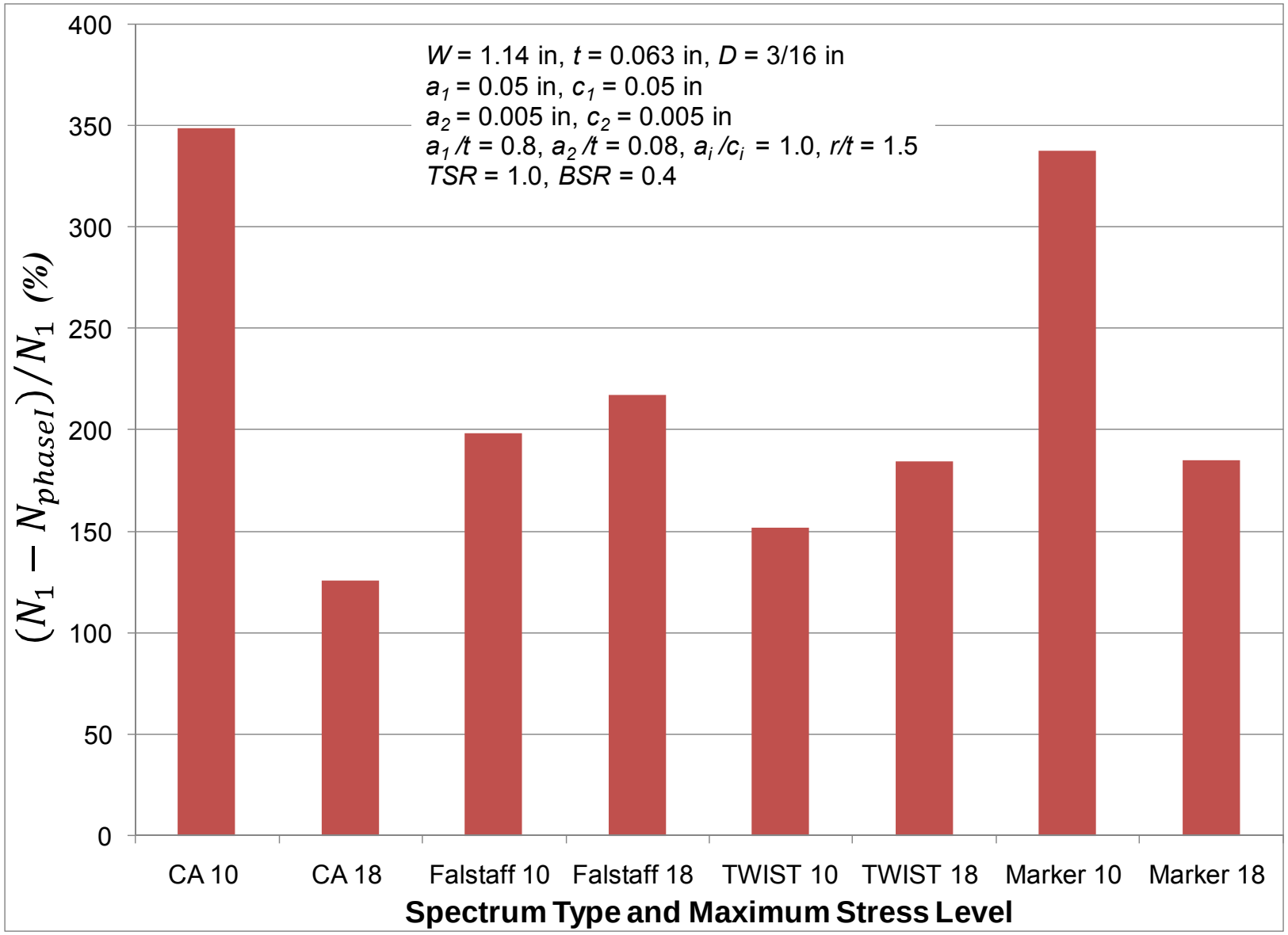
a_2 = 0.005 in, c_2 = 0.005 in

a_1/t = 0.8, a_2/t = 0.08, a_i/c_i = 1.0, r/t = 1.5

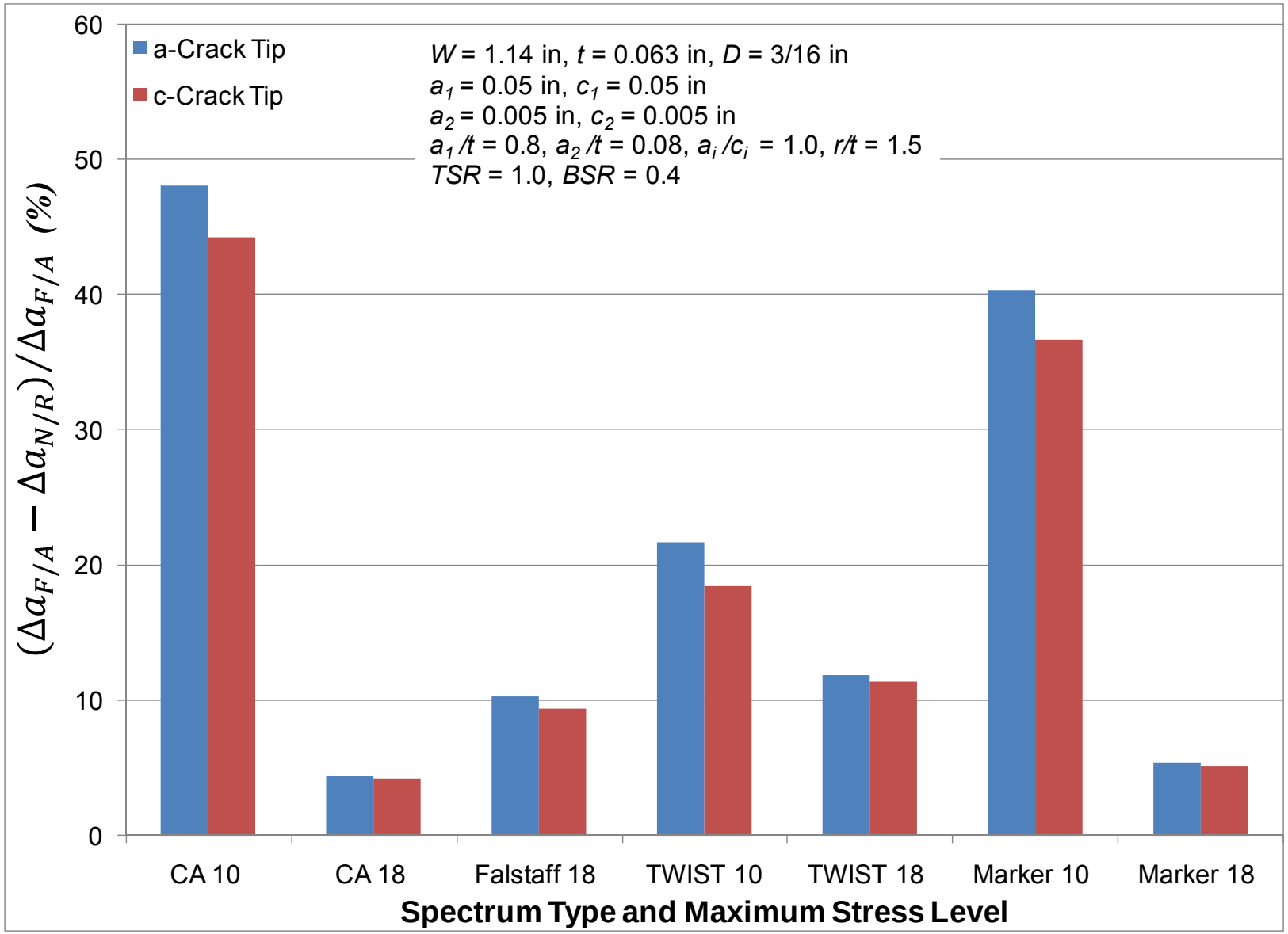
TSR = 1.0, BSR = 0.4



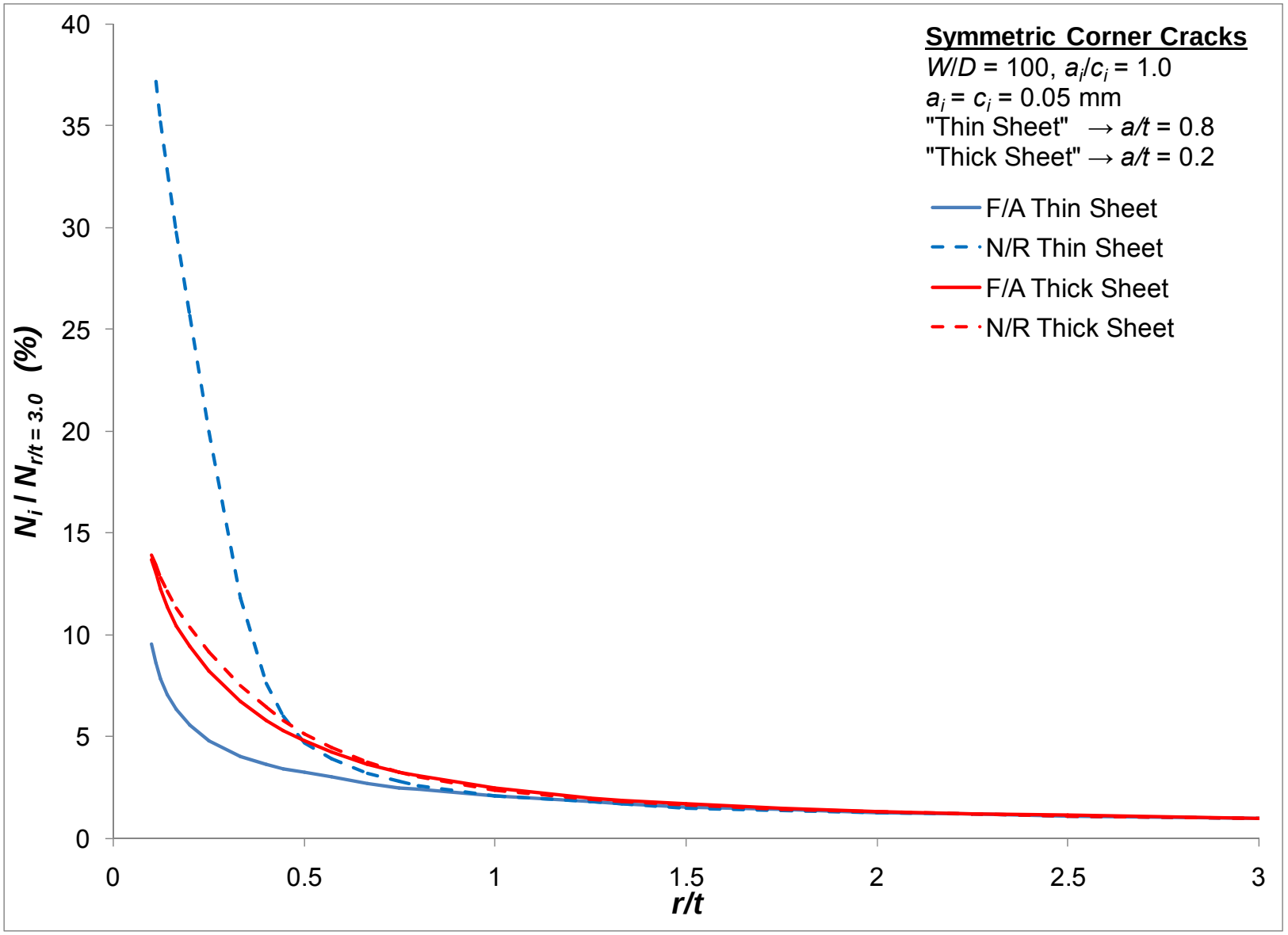
Effect on Continuing Damage Scenario Phase I Life



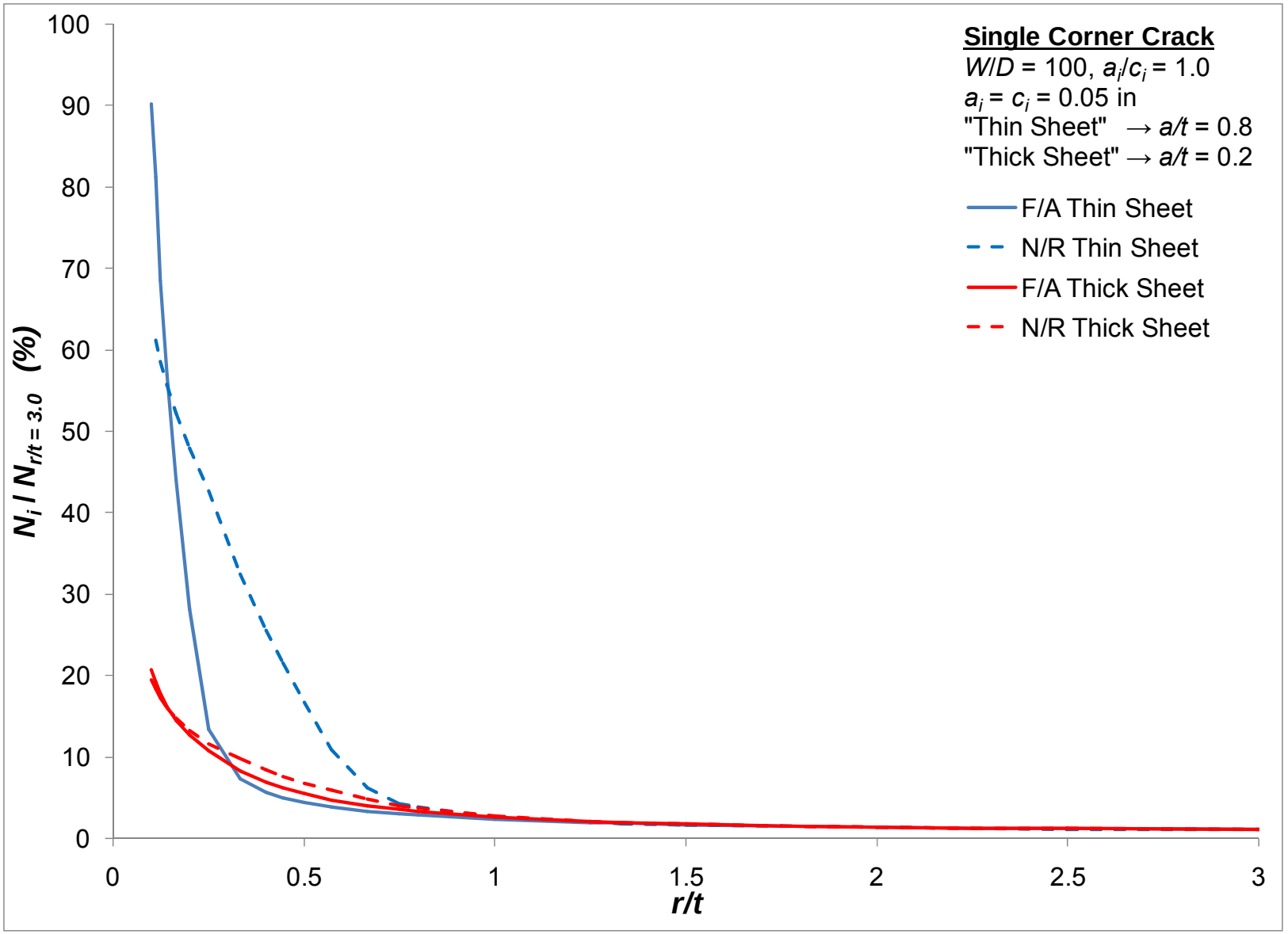
Effect on Continuing Damage Scenario Phase I Crack Length



Effect of *r/t* – Symmetric Corner Cracks



Effect of *r/t* – Single Corner Crack



Conclusions

- Verification
  - *hp*-version FEA + Splitting Scheme = Accurate *K*-Solutions
- Validation
  - Fatigue life predictions are slightly conservative
- 5,672,700 *K* solutions for unsymmetric corner cracks at a hole subject to tension, bending, bearing
  - Solutions available in tabular form – currently in *AFGROW*
    - *75 – 1.5MB ASCII files*
  - Source code for multi-dimensional interpolation also available

Significance

- Single vs. Double Cracks
  - Difference always larger for single cracks
- Effect on Fatigue Life
  - Small cracks in thin sheets: 20-50%
  - Small cracks in thick sheets: 25-45%
  - Large cracks in thin sheets: 90-300%
  - Continuing damage scenario: 125-350%
- Effect on Inspections
  - Possibility of initial inspection not early enough in aircraft life
  - Possibility of recurring inspections not occurring as frequently as required
- Effect of *r/t*
  - Significant for large cracks in thin sheets
  - Negligible for small cracks in thick sheets