AFGROW User Workshop 2015

Influence of 'a' crack tip material properties on corner crack shape and aspect ratio

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Crack Aspect Ratio

(Pilarczyk, 2011)

- A/C = constant?
  - Historically A-10 DTAs Assumed A/C = Constant
  - Retardation Parameters Derived with this Approach
  - Some Consideration Recently to Change to A/C ≠ Constant
    - What are the Impacts???
    - Recent Studies Indicate A/C ≠ Constant Over-Predicting Bore Crack Growth (Classic AFGROW Model (a@80deg, c@5deg)
- This Presentation Evaluates Impacts from Changing A/C ≠ Constant

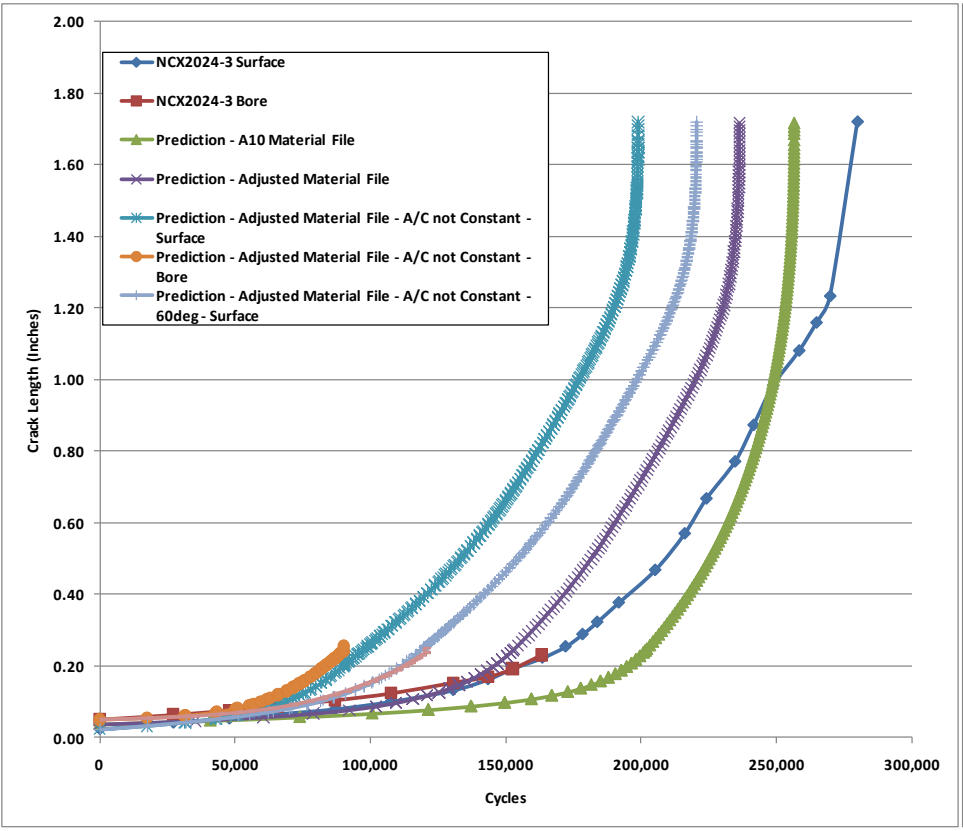
Comparison to Constant Amplitude Data

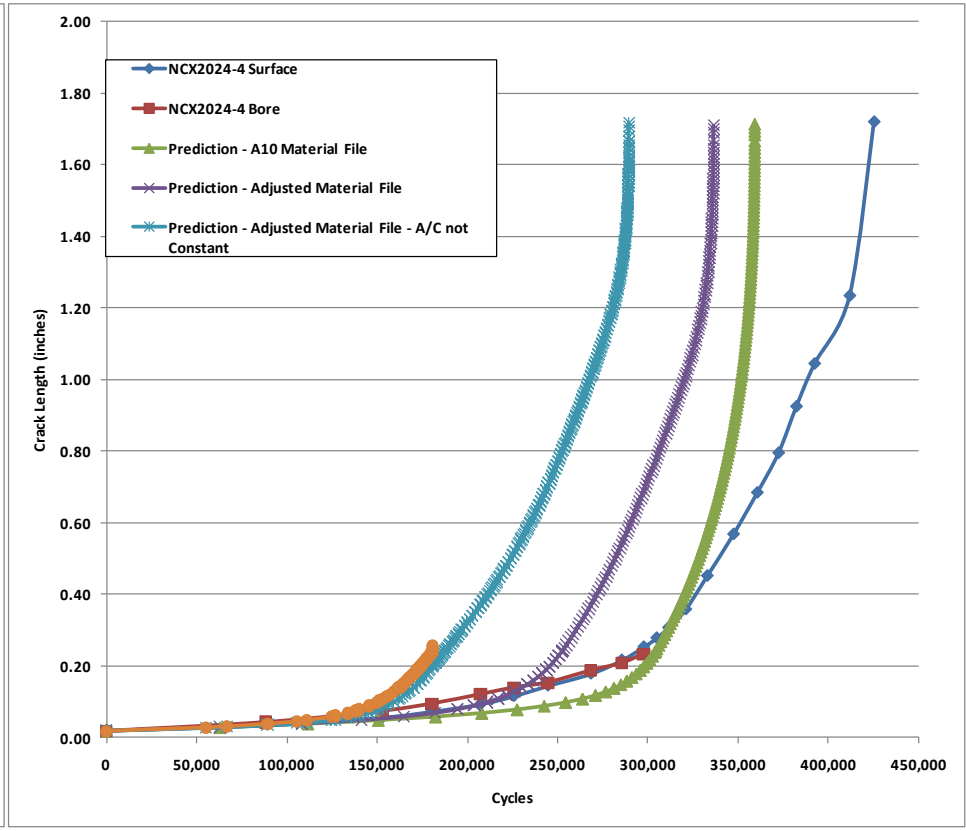
(Pilarczyk, 2011)

Carlson/Pilarczyk Theses

- A/C Constant, Avg. IFS Predicts 82% of Tested Life
- A/C ≠ Constant Predicts 70% of Tested Life

- Test Parameters
  - 2024-T351 Plate
  - W=4", t=0.25", B=2", D=0.5"
  - CA, R=0.1, Max Stress = 10ksi





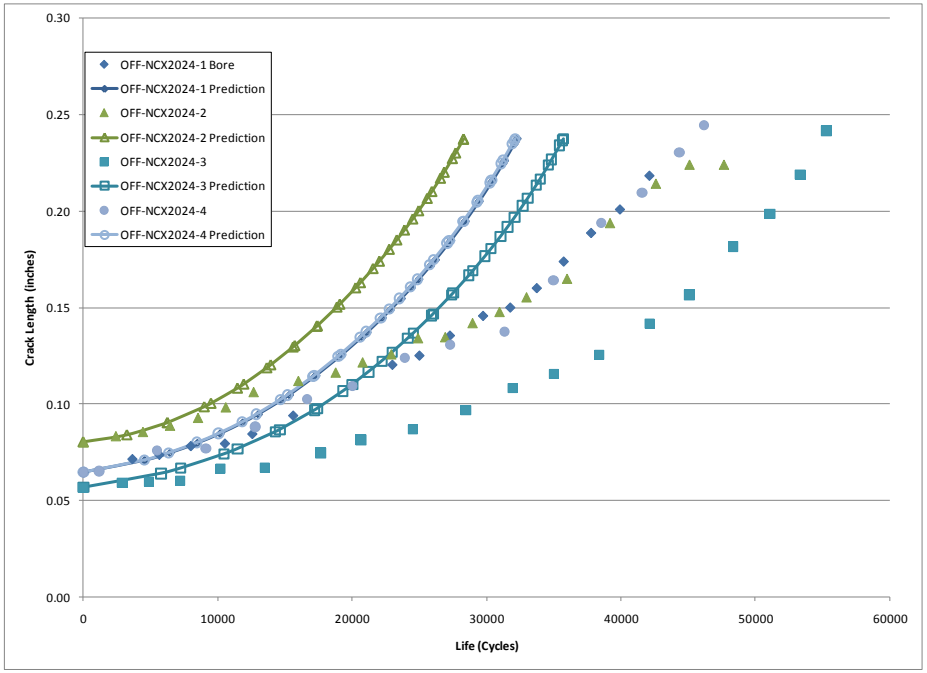
Comparison to Constant Amplitude Data

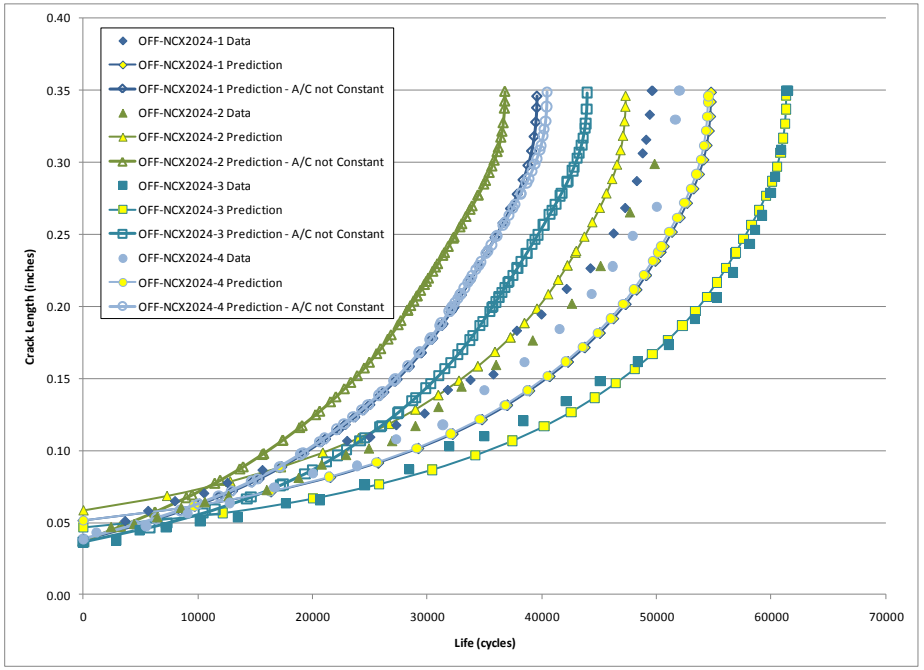
(Pilarczyk, 2011)

Andrew/Warner Theses

- A/C Constant, Avg. IFS Predicts 101.6% of Tested Life
- A/C ≠ Constant Predicts 75% of Tested Life

- Test Parameters
  - 2024-T351 Plate
  - W=4”, t=0.25”, B=0.6”, D=0.5”, e/D=1.2
  - CA, R=0.1, Max Stress = 10ksi



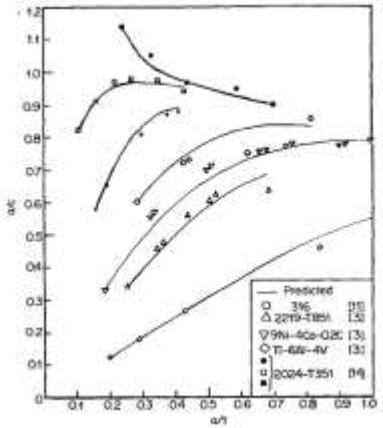


* Avg. IFS for A/C Constant Predictions

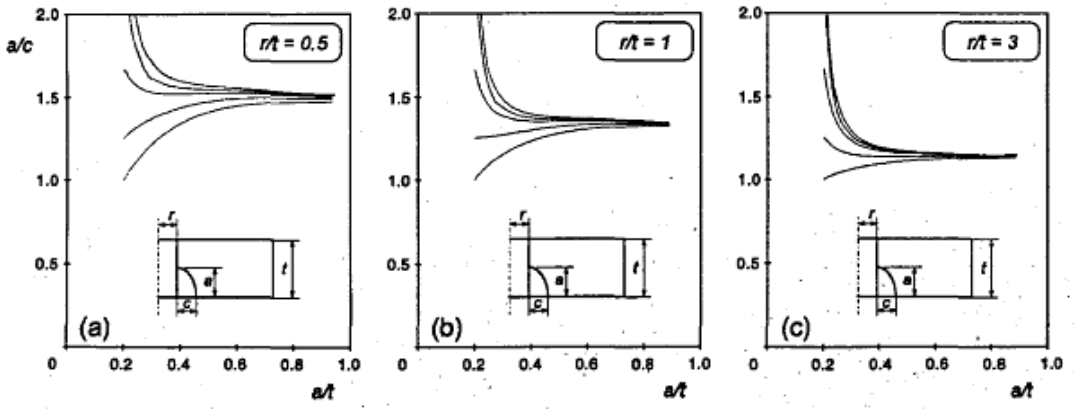
Equilibrium Crack Aspect Ratio

(Pilarczyk, 2011)

- **Equilibrium Crack Aspect Ratio**
  - **For some situations, Cracks will Tend to Grow to an Equilibrium Crack Aspect Ratio (Ref 1, 2, 3)**
    - **Study focused on open hole test data, tension loading**
    - **Function of material (Paris exponent), hole radius/thickness ratio**
    - **Just starting to dig in…**



Crack aspect ratio variation for surface cracks, tension loading, various starting aspect ratios [Ref 1]



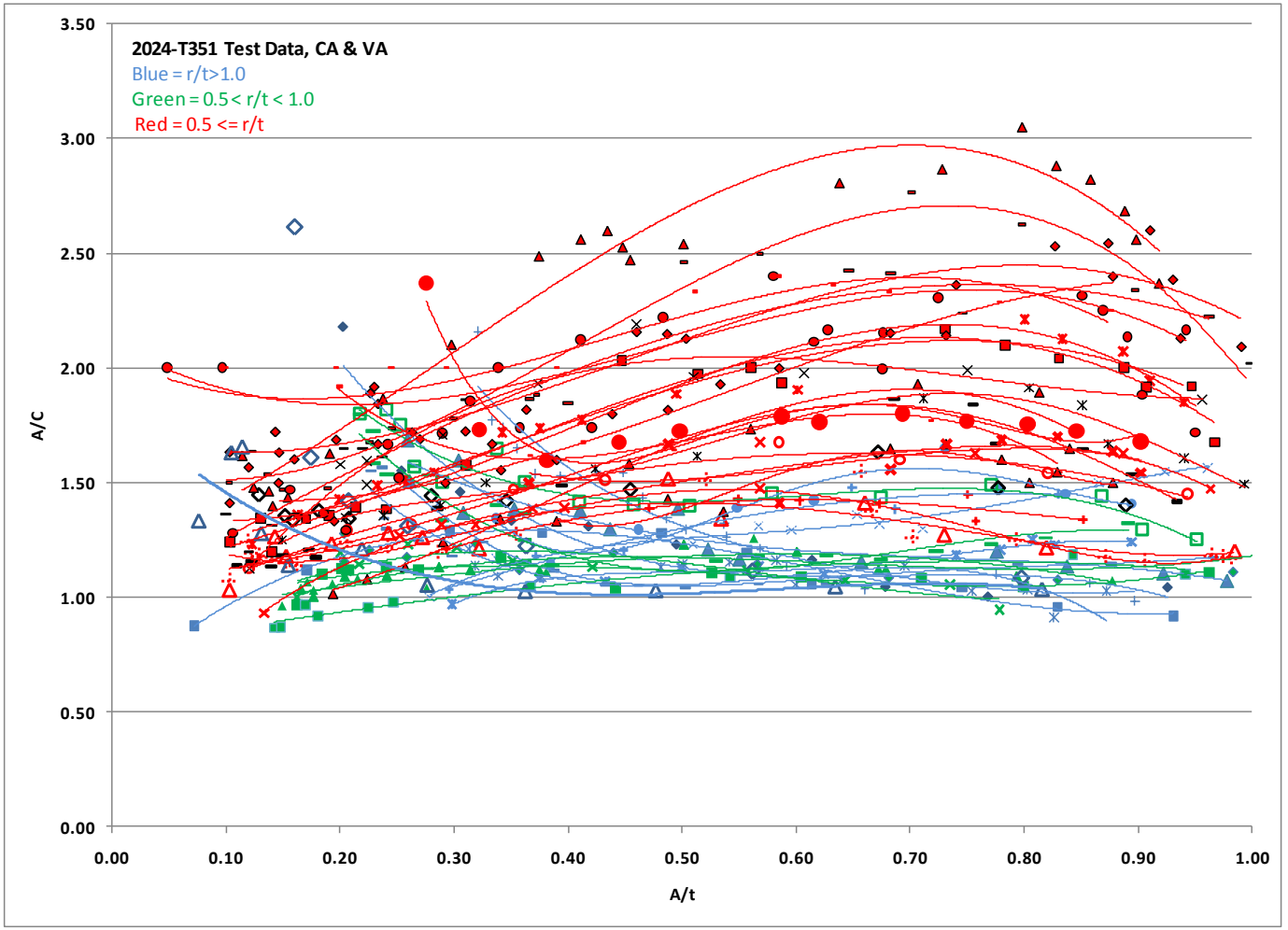
Example: Numerical prediction of crack aspect ratio variation for corner cracks at a hole, tension loading, various starting aspect ratios [Ref 2]

Ref 1: Shang-Xian, W. (1985). Shape Change of Surface Crack During Fatigue Crack Growth. Engng Fract. Mech. 22, 897-913.
Ref 2: Lin, X.B., Smith, R.A. (1988). Fatigue Shape Analysis for Corner Cracks at Fastener Holes. Engng Fract. Mech. 59, 73-87.
Ref 3: Seog Oh, C., Park, P., Hak Huh, Y., Gyu Ko, S., Young Hwang, D., Mo An, H. (2005). Fatigue Crack Growth Behavior of Corner Cracks under LBH Loading. Key Engng Mater. 297-300, 128-134.

Equilibrium Crack Aspect Ratio, Cont.

(Pilarczyk, 2011)

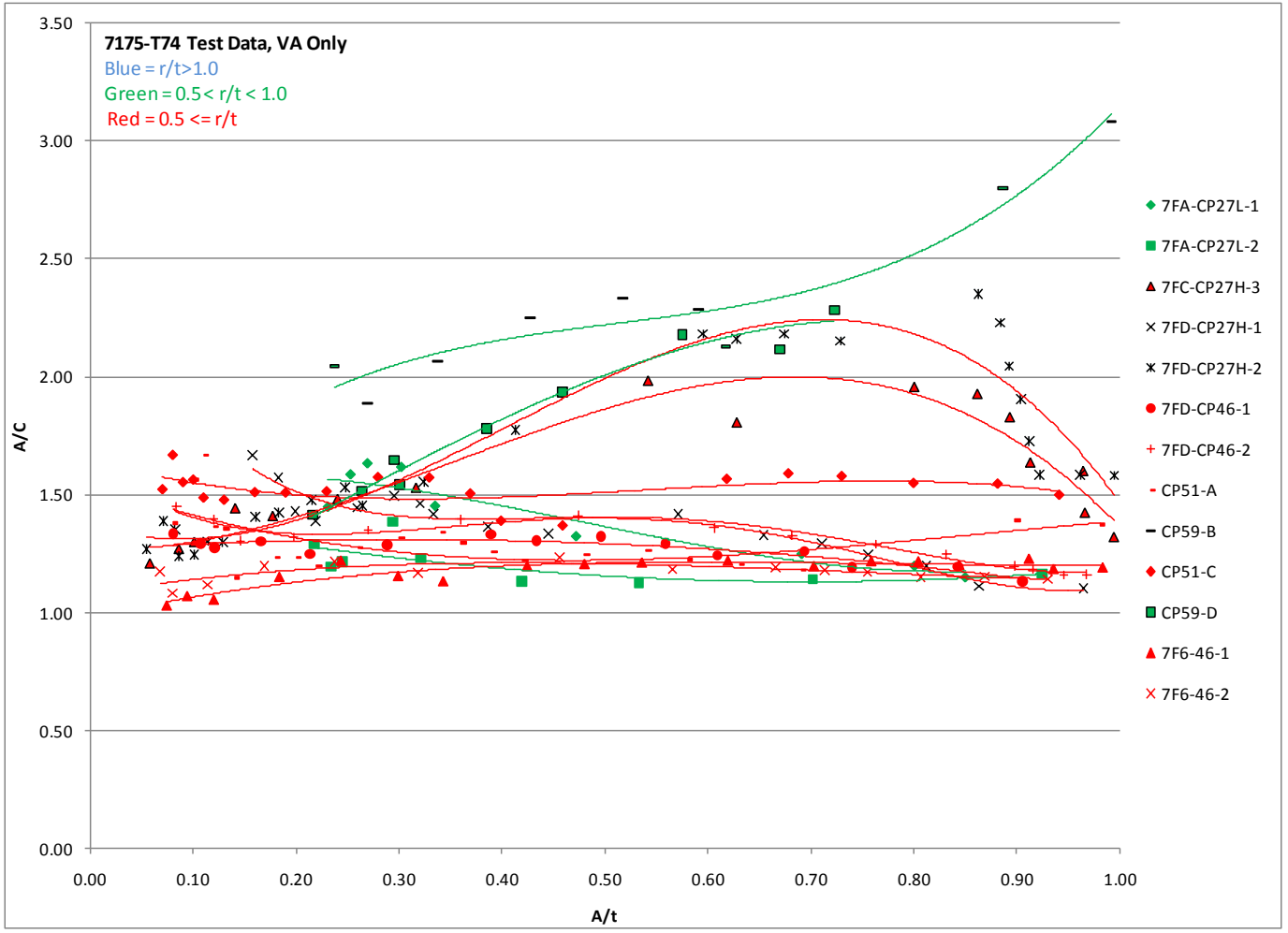
- 2024-T351 Data



Equilibrium Crack Aspect Ratio, Cont.

(Pilarczyk, 2011)

- 7175-T74 Data



Summary/Conclusions

(Pilarczyk, 2011)

- Going Forward
  - If A/C = Constant, What Should be the IFS for SOLR Correlation Given that A≠C for Test Coupon?
    - Average Flaw Size?
    - Surface Flaw Size?
  - r/t ratio is an Important Parameter to Consider when Developing Coupon Test Plans
  - What is the Appropriate K Representation for Bore Crack Growth?
    - Classic – Typically 10deg
    - Advanced – Local Peak
    - Tune to Match Equilibrium Aspect Ratio from Test with Bore Angle???

Summary/Conclusions, Cont.

(Pilarczyk, 2011)

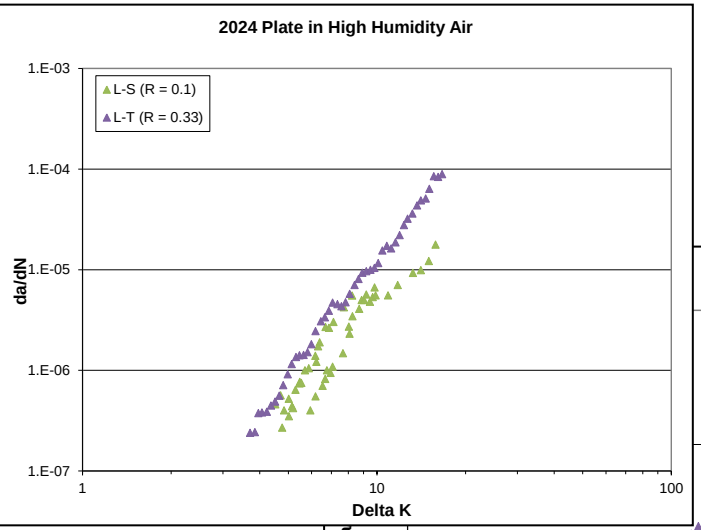
- **What is the Appropriate K Representation for Bore Crack Growth?, Cont.**
  - **Multi-point Solution for Single Corner Crack at a Hole will be Available in Next AFGROW Release**
    - **Evaluate How Well this Model Can Predict Corner Crack Growth**
- **At this point, A/C=Constant is the Best Approach Until Further Investigation is Complete.**

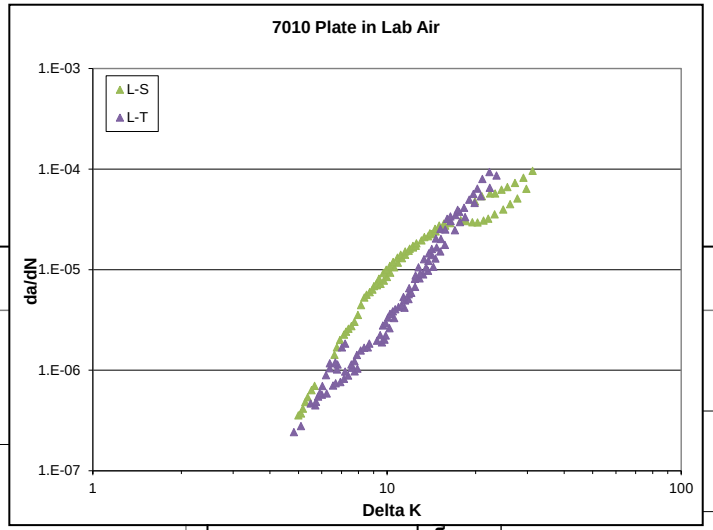
FCGR L-S Testing

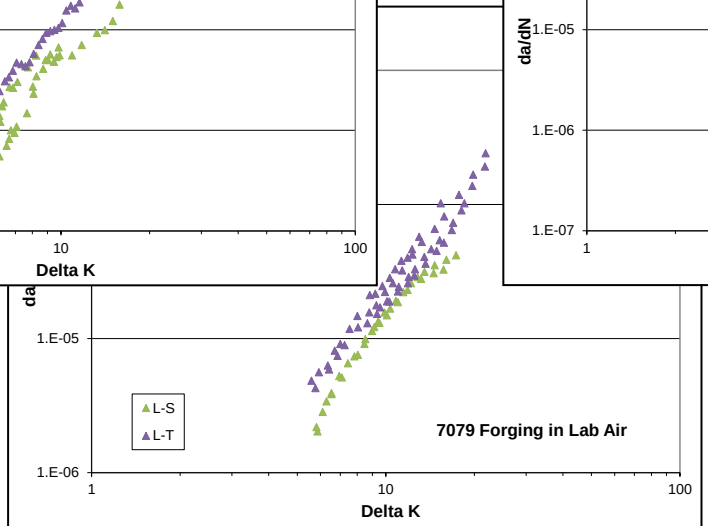
Test Type	Material	Orientation	Geometry	Loading	Specimens
FCGR	2024-T351	L-S	ESE(T)	0.1, 0.5	6
FCGR	7175-T74	L-S	ESE(T)	0.1, 0.5	6

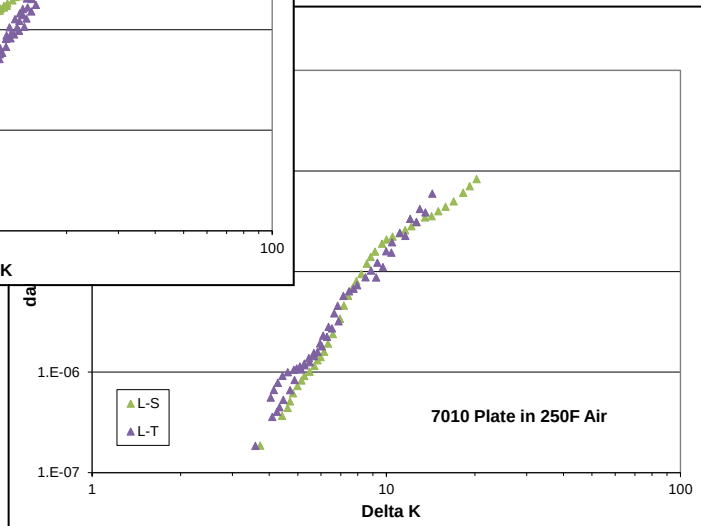
NASMAT Data

Alloy	Form	Direction	R	Atmosphere	Temperature
2024-T851	Plate	L-S	0.1	HHA	Room
7010-T73651	Plate	L-S	0.1	AIR	250F
7010-T73651	Plate	L-S	0.1	LA	Room
7079-T652	Forging	L-S	0.33	LA	Room



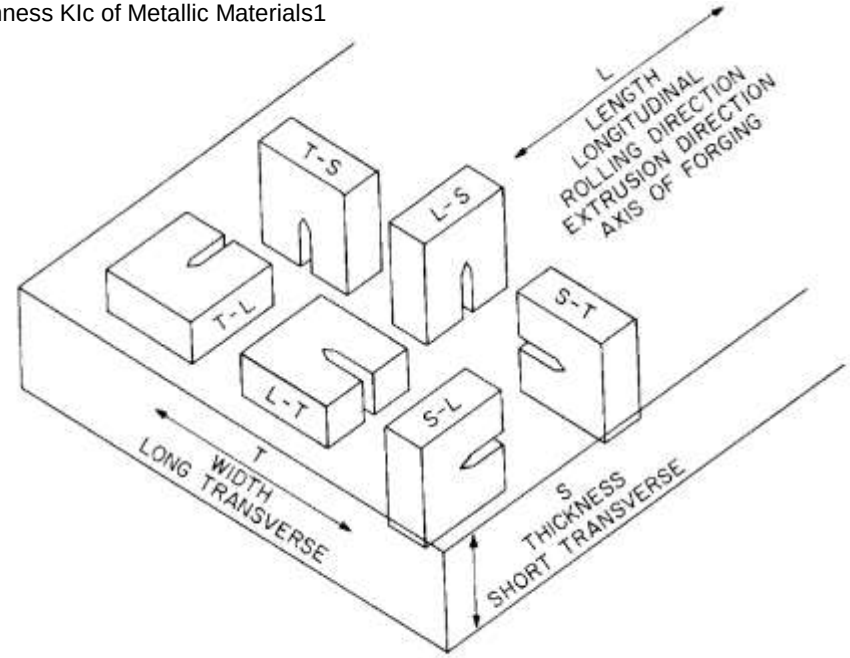






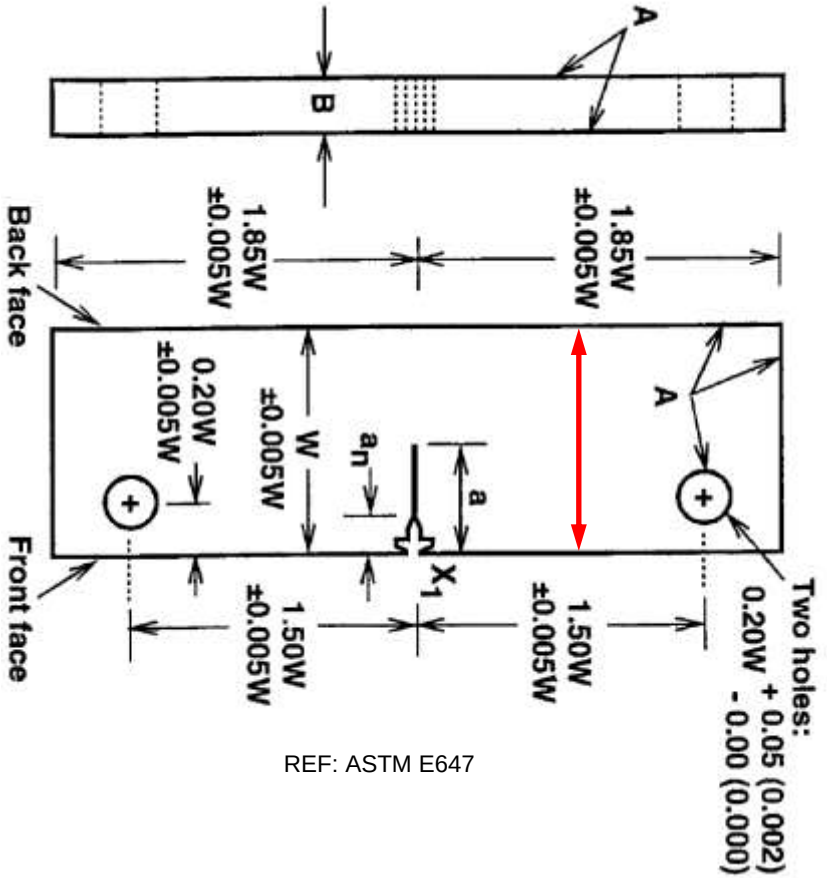
FCGR L-S Testing: Definition of L-S

REF: ASTM E399 Standard Test Method for Linear-Elastic Plane-Strain Fracture Toughness KIc of Metallic Materials1

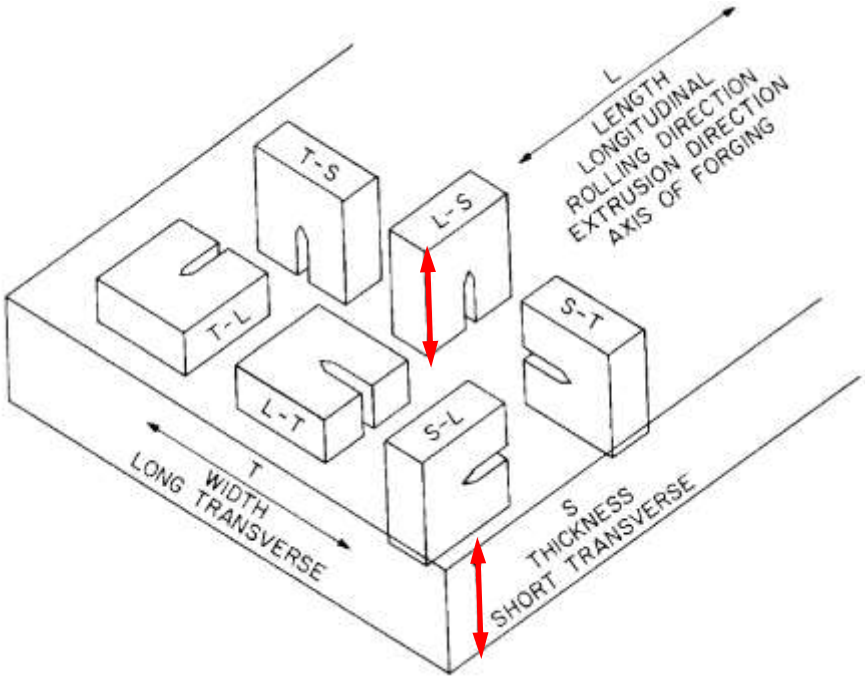


(a) Rectangular Sections—Specimens Aligned with Reference Directions

FCGR L-S Testing: Coupon type selection



REF: ASTM E647

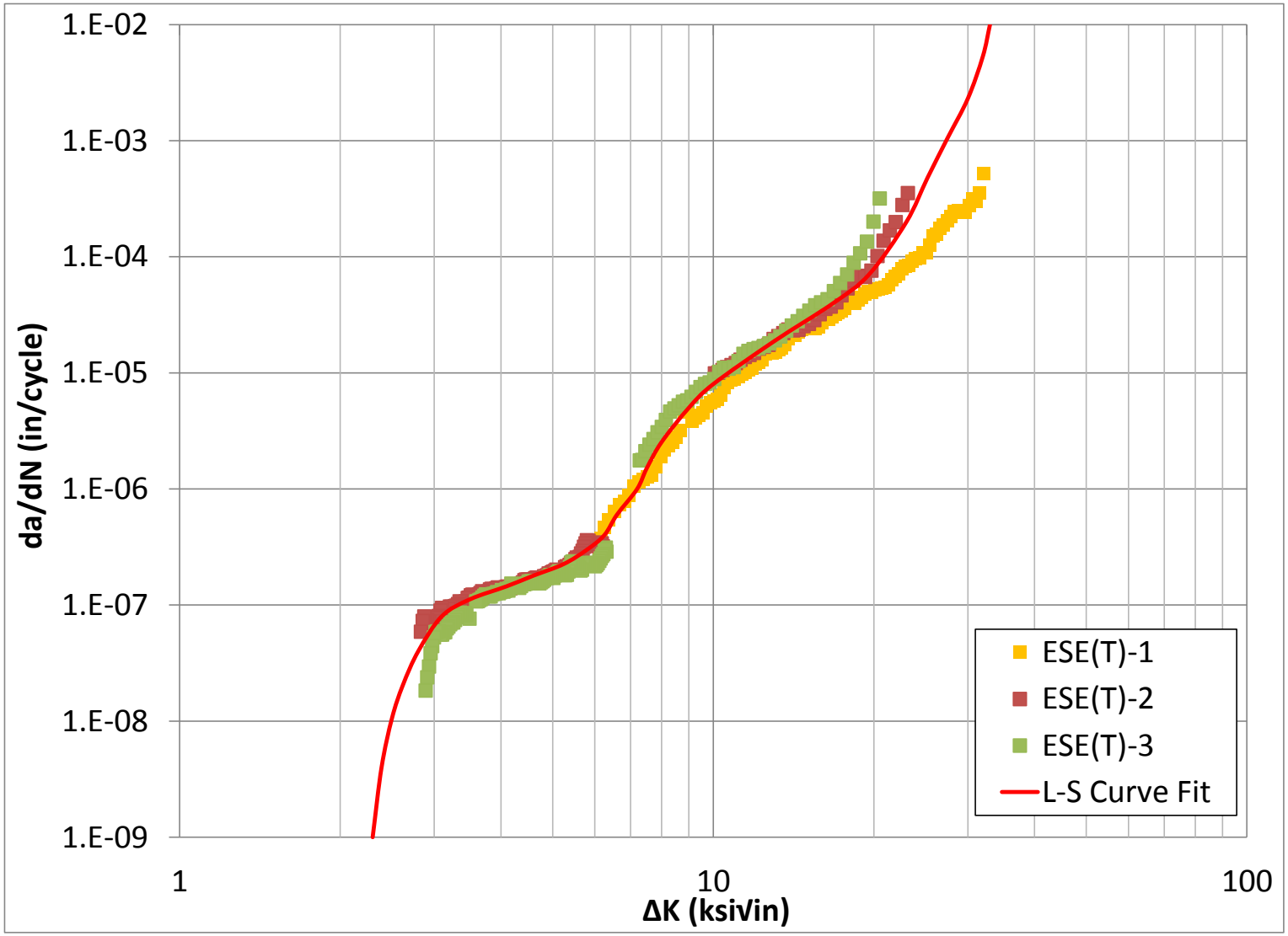


REF: ASTM E399

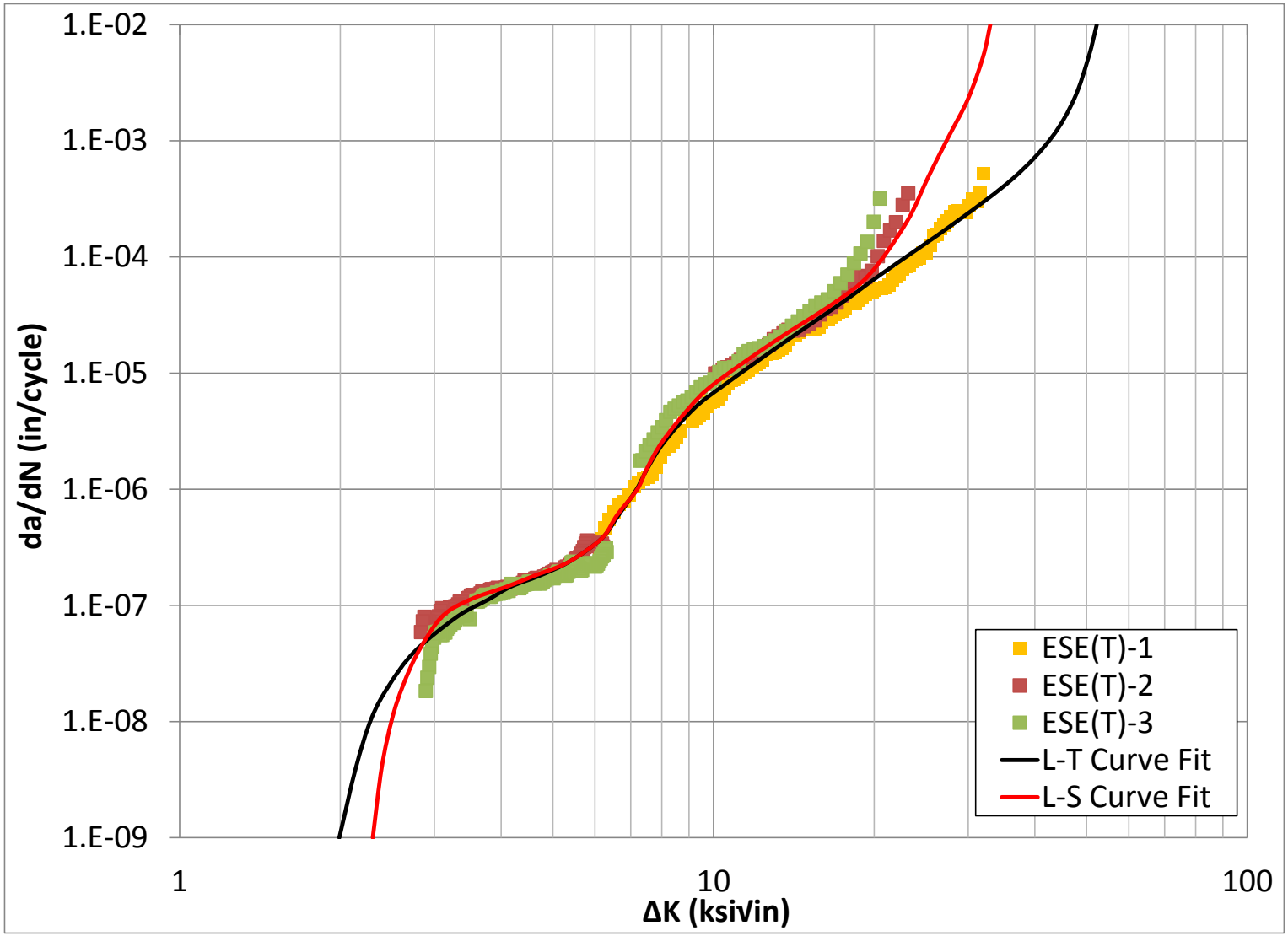
ESE(T):

THE ECCENTRICALLY-LOADED SINGLE EDGE CRACK TENSION SPECIMEN

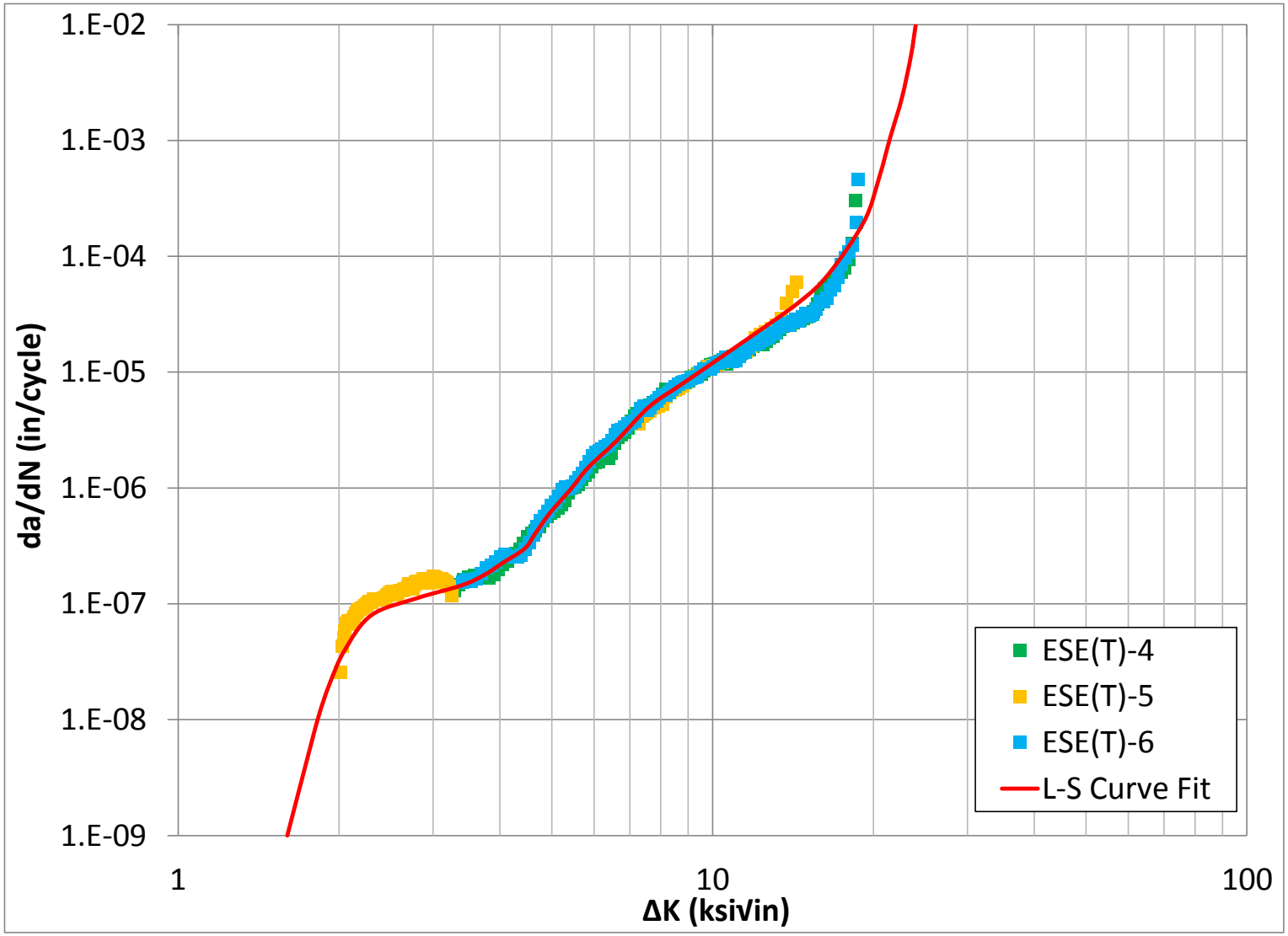
Curve Fit of Test Data: 2024-T351 | R=0.1



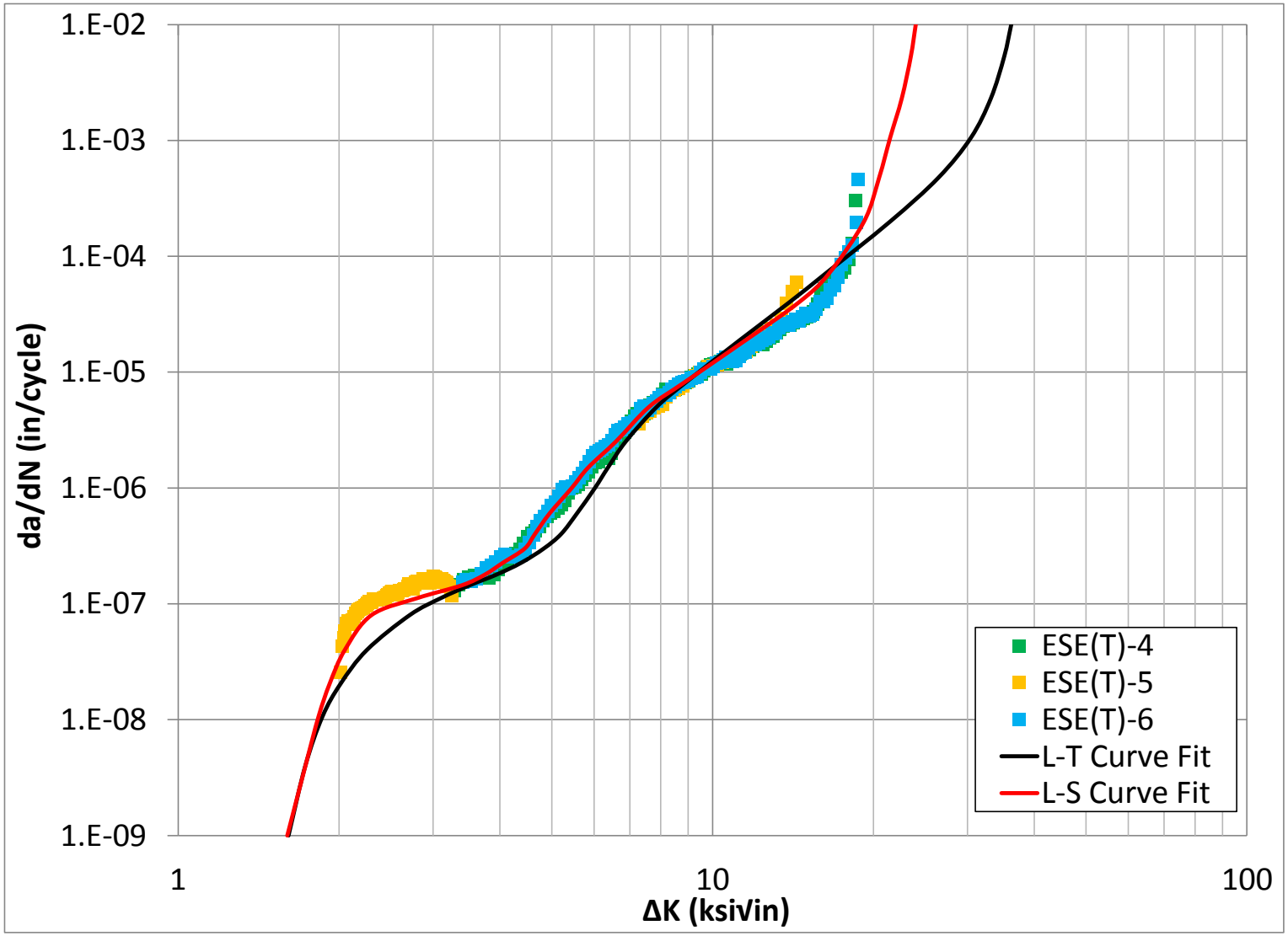
Curve Fit of Test Data: 2024-T351 | R=0.1



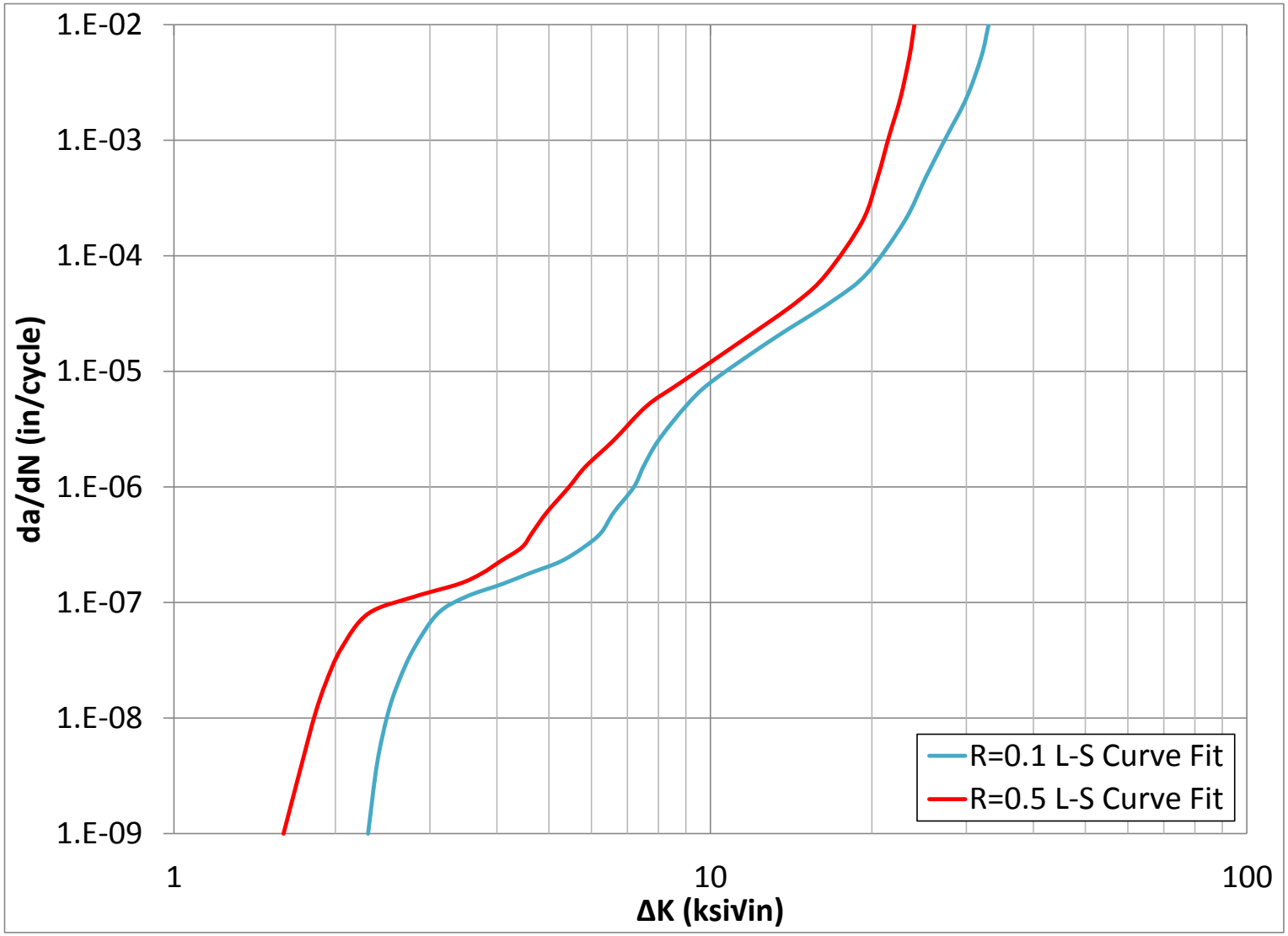
Curve Fit of Test Data: 2024-T351 | R=0.5



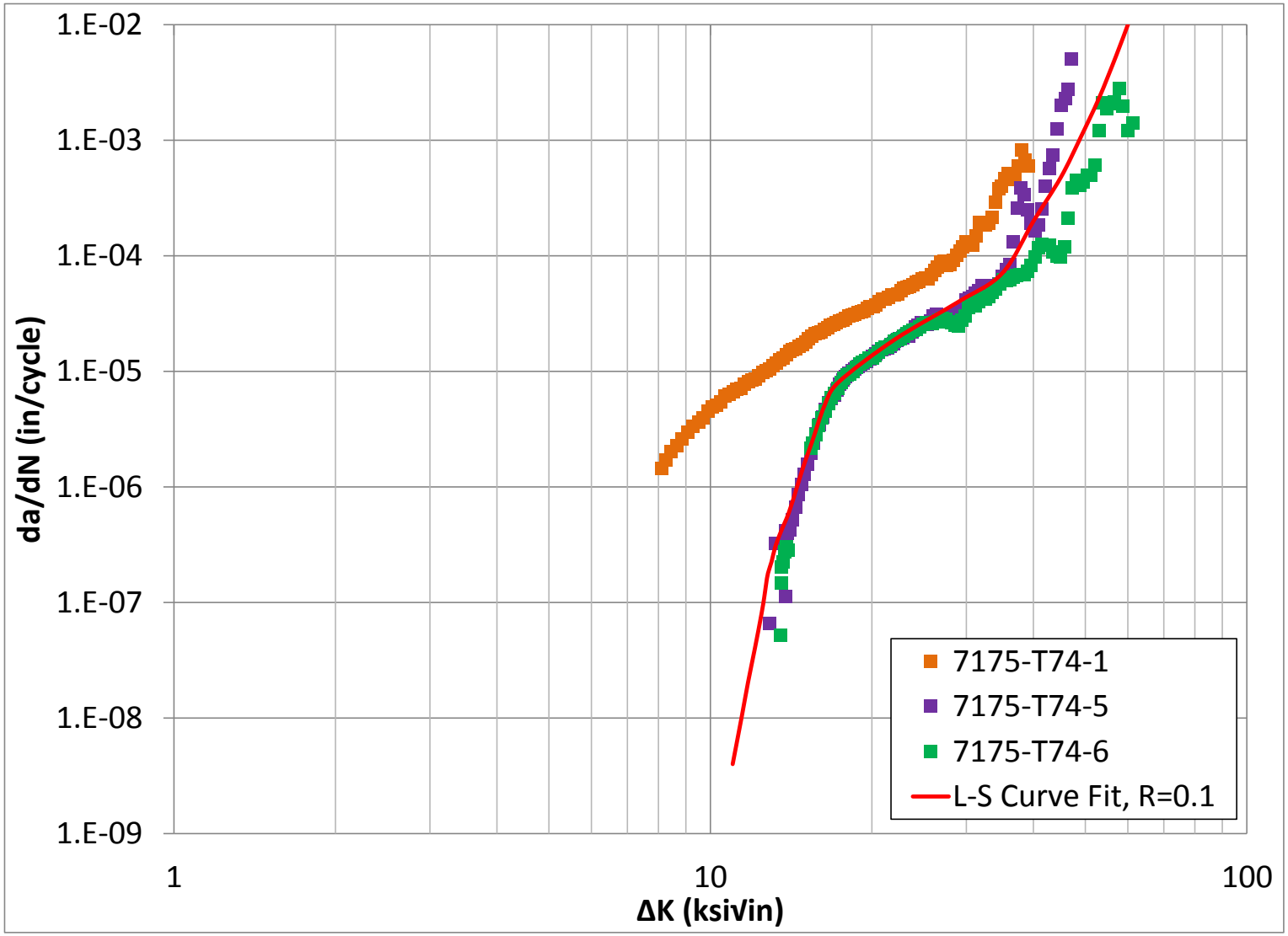
Curve Fit of Test Data: 2024-T351 | R=0.5



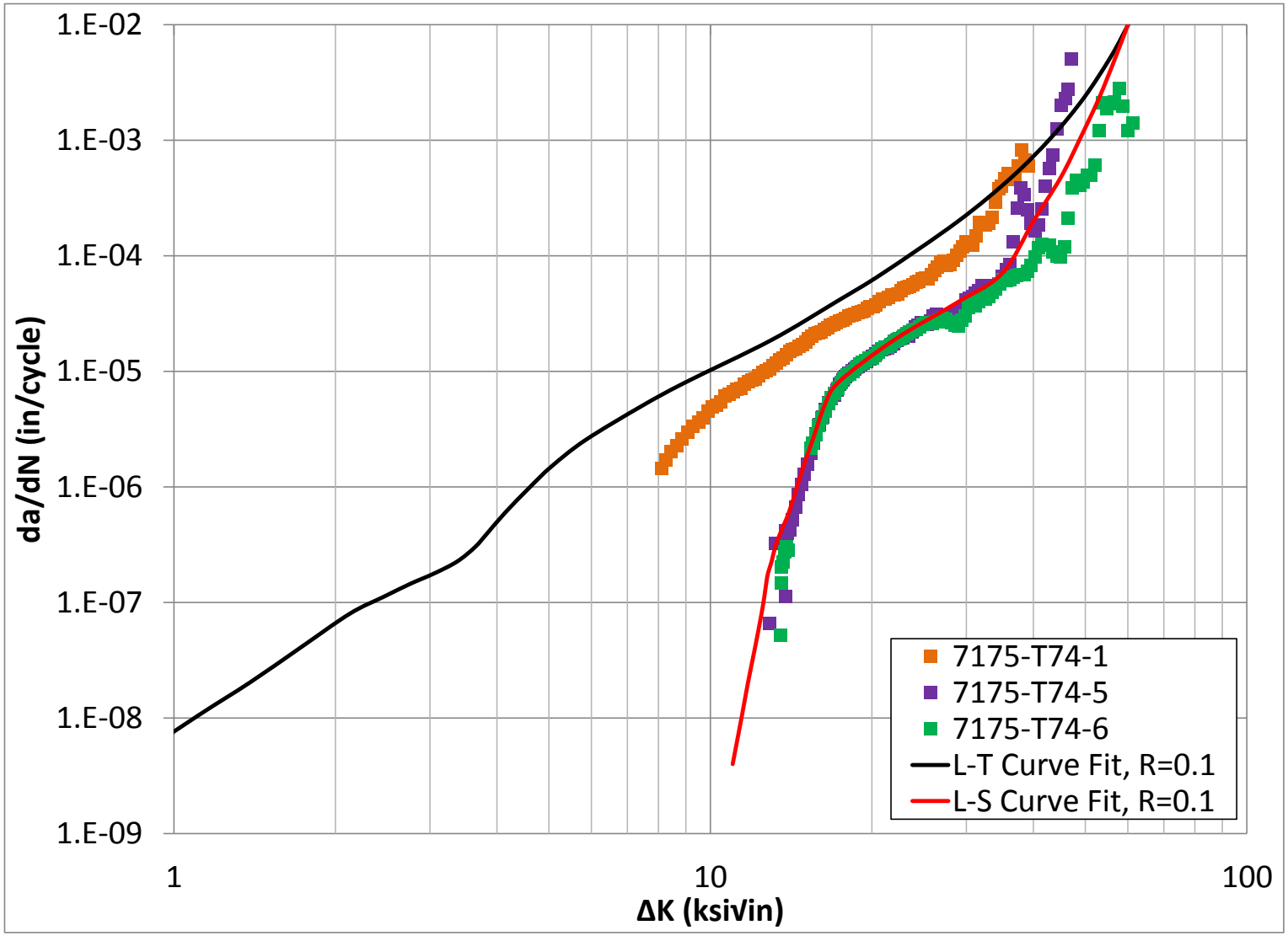
Curve Fit of Test Data: 2024-T351



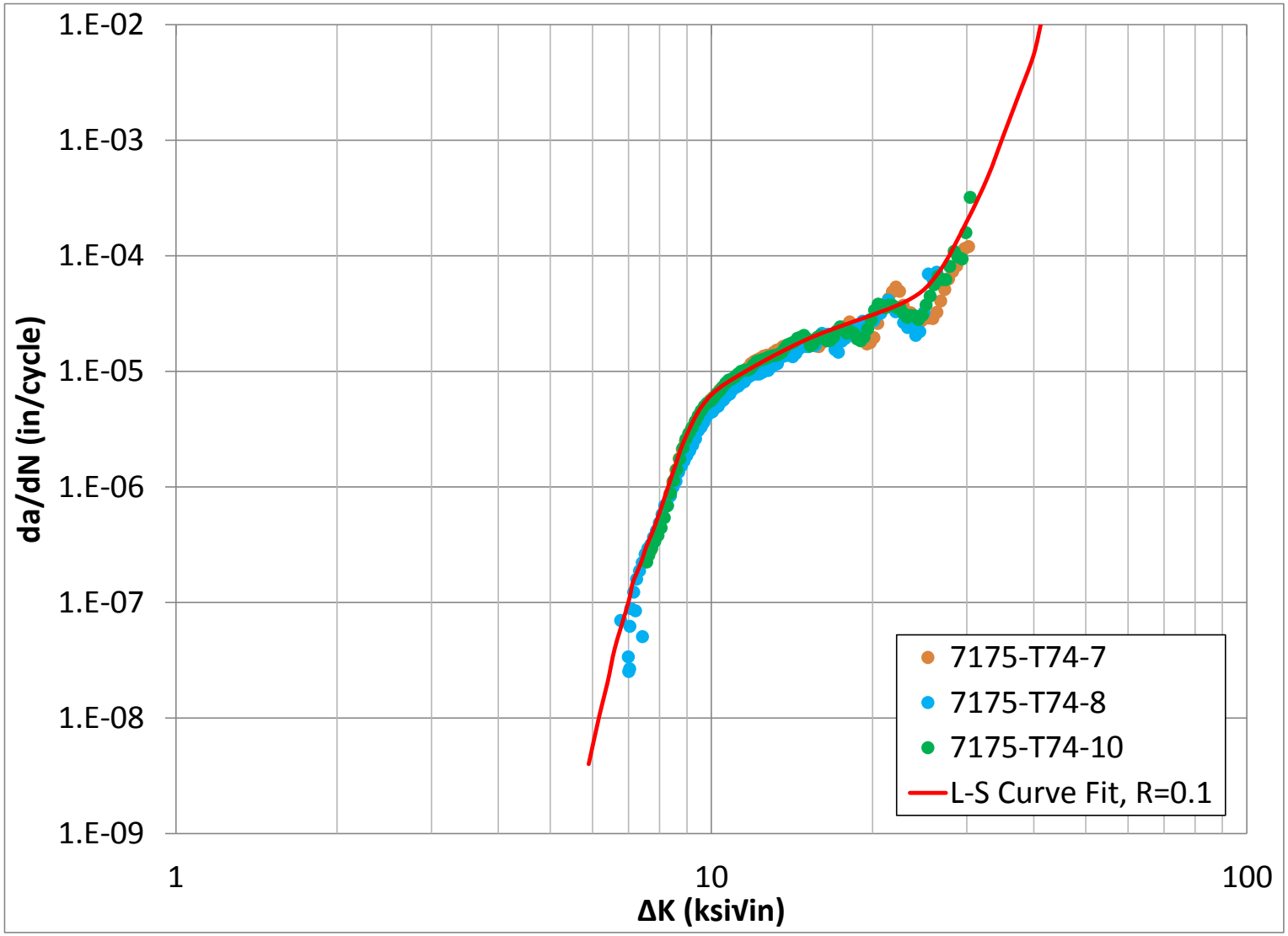
Curve Fit of Test Data: 7175-T74 | R=0.1



Curve Fit of Test Data: 7175-T74 | R=0.1



Curve Fit of Test Data: 7175-T74 | R=0.5



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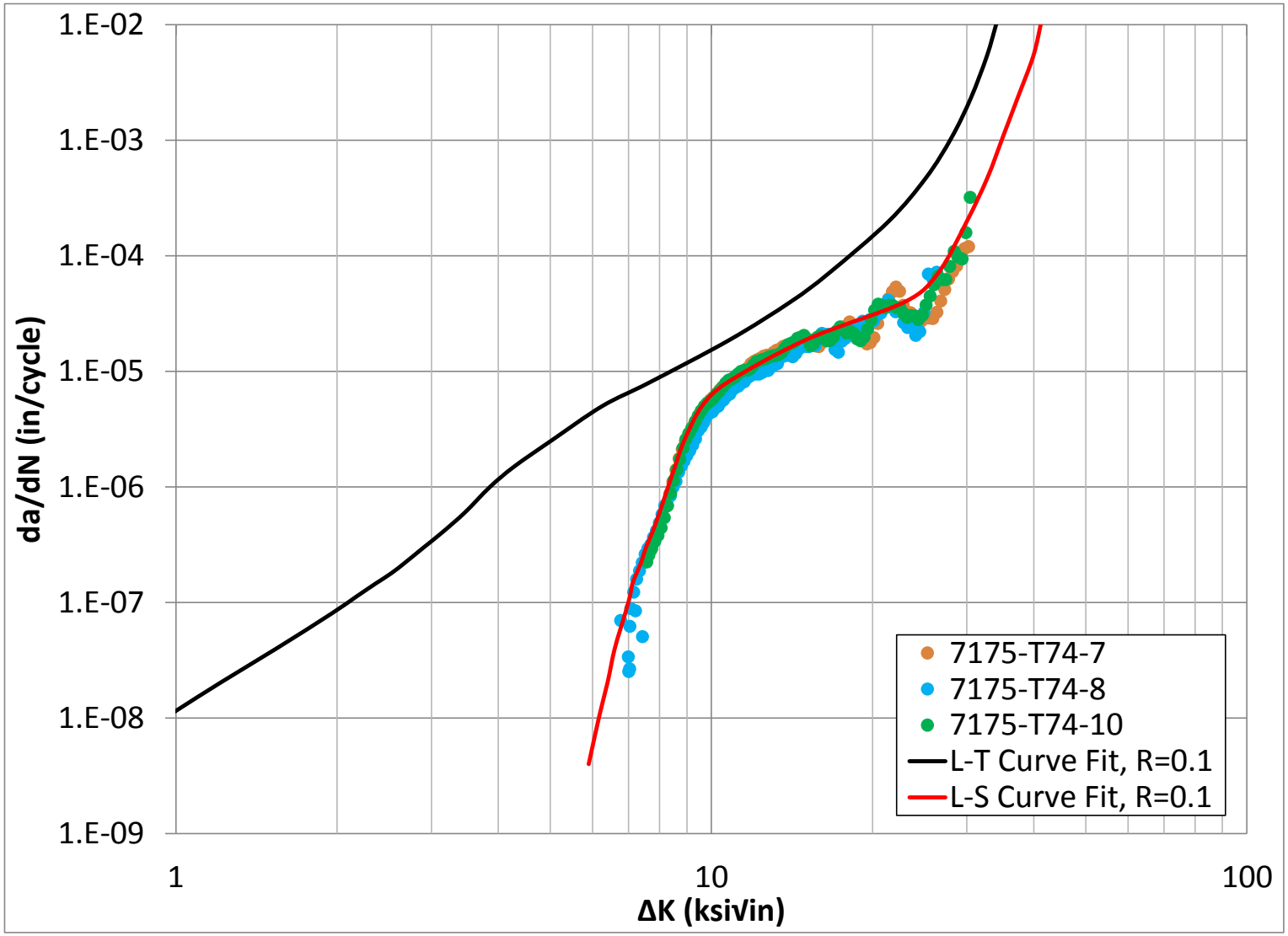
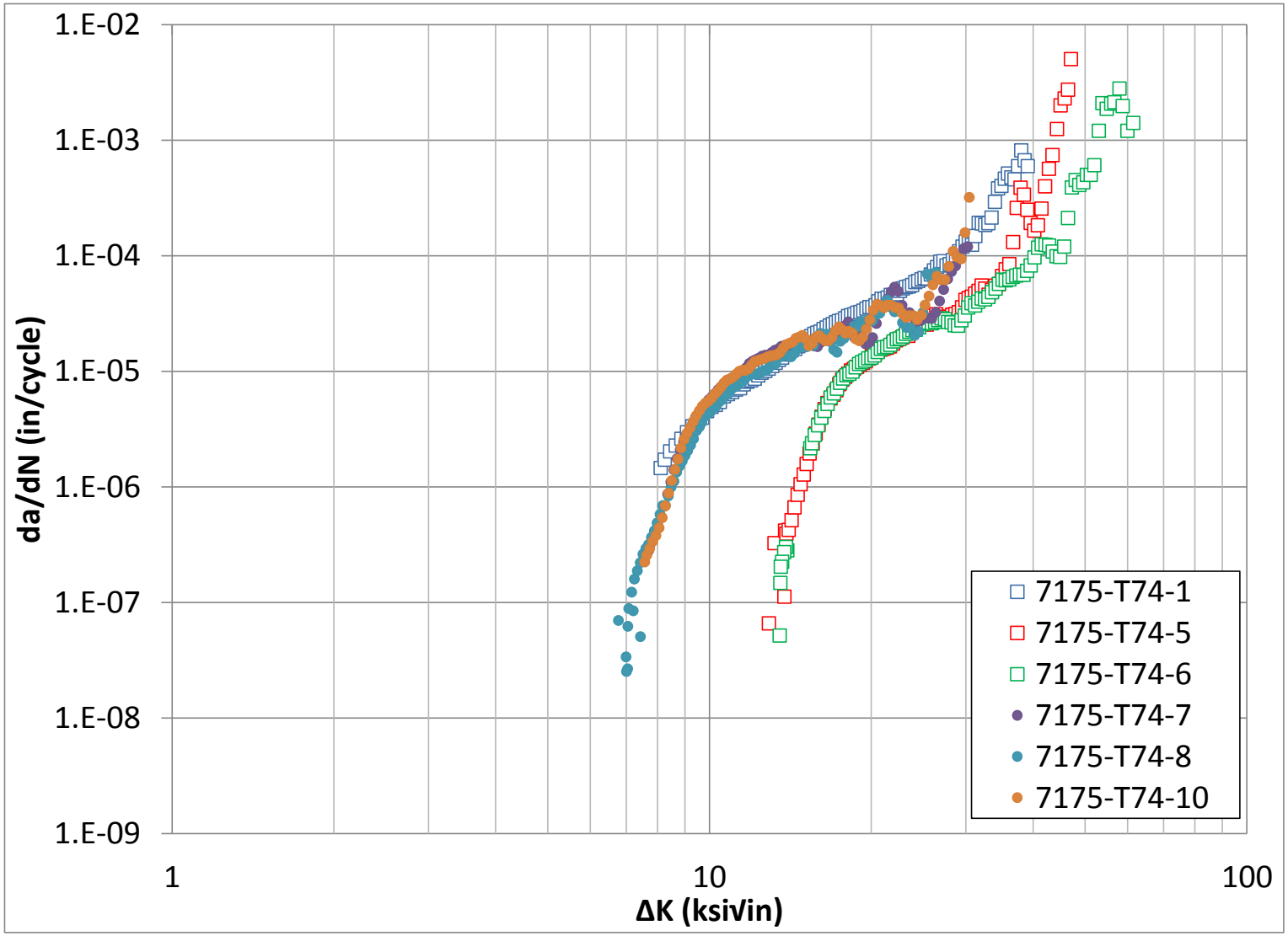
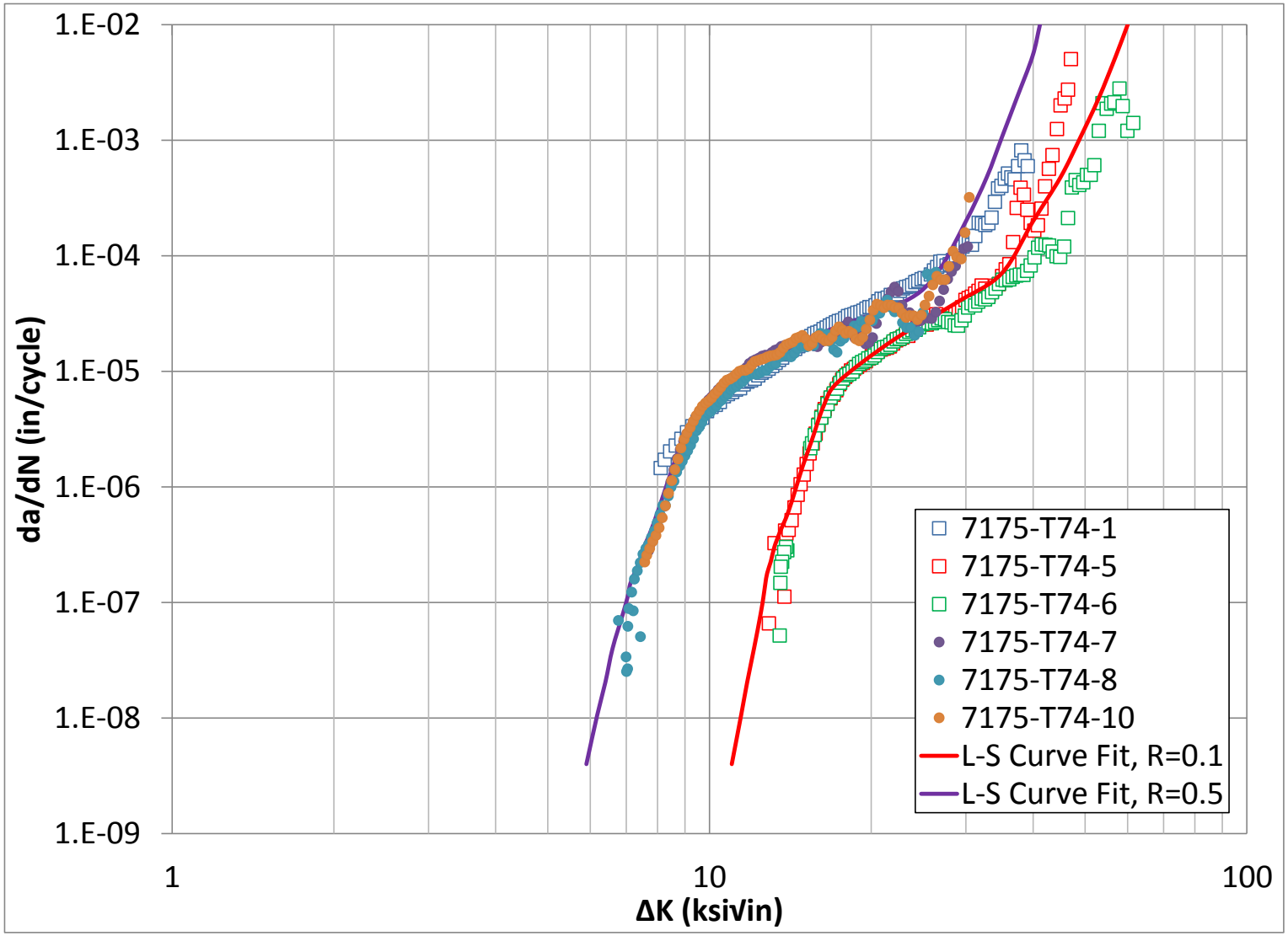


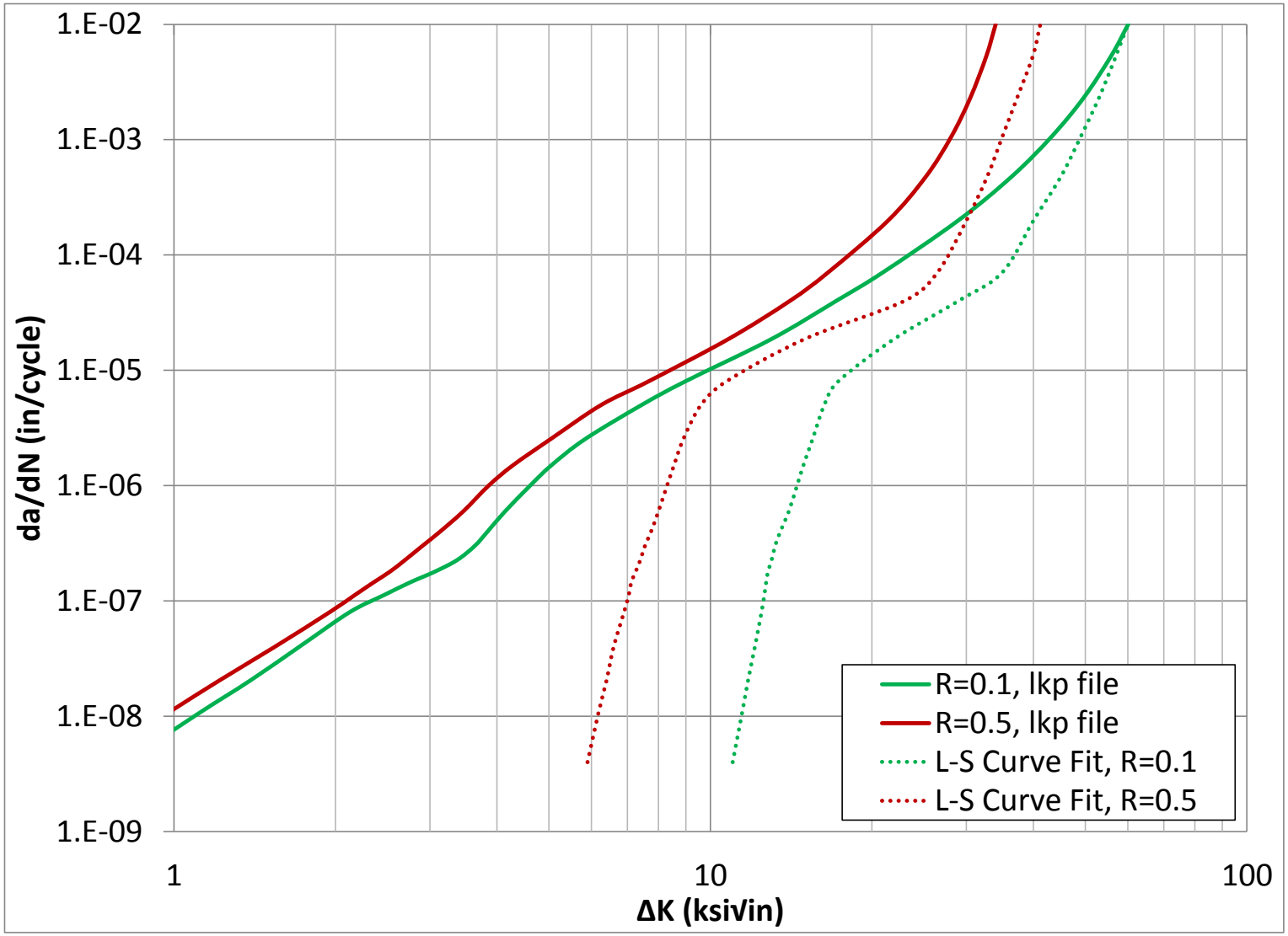
Curve Fit of Test Data: 7175-T74 | L-S



Curve Fit of Test Data: 7175-T74 | L-S



Curve Fit of Test Data: 7175-T74 | L-T vs L-S



Curve Fit of Test Data: 7175-T74 | L-T vs L-S

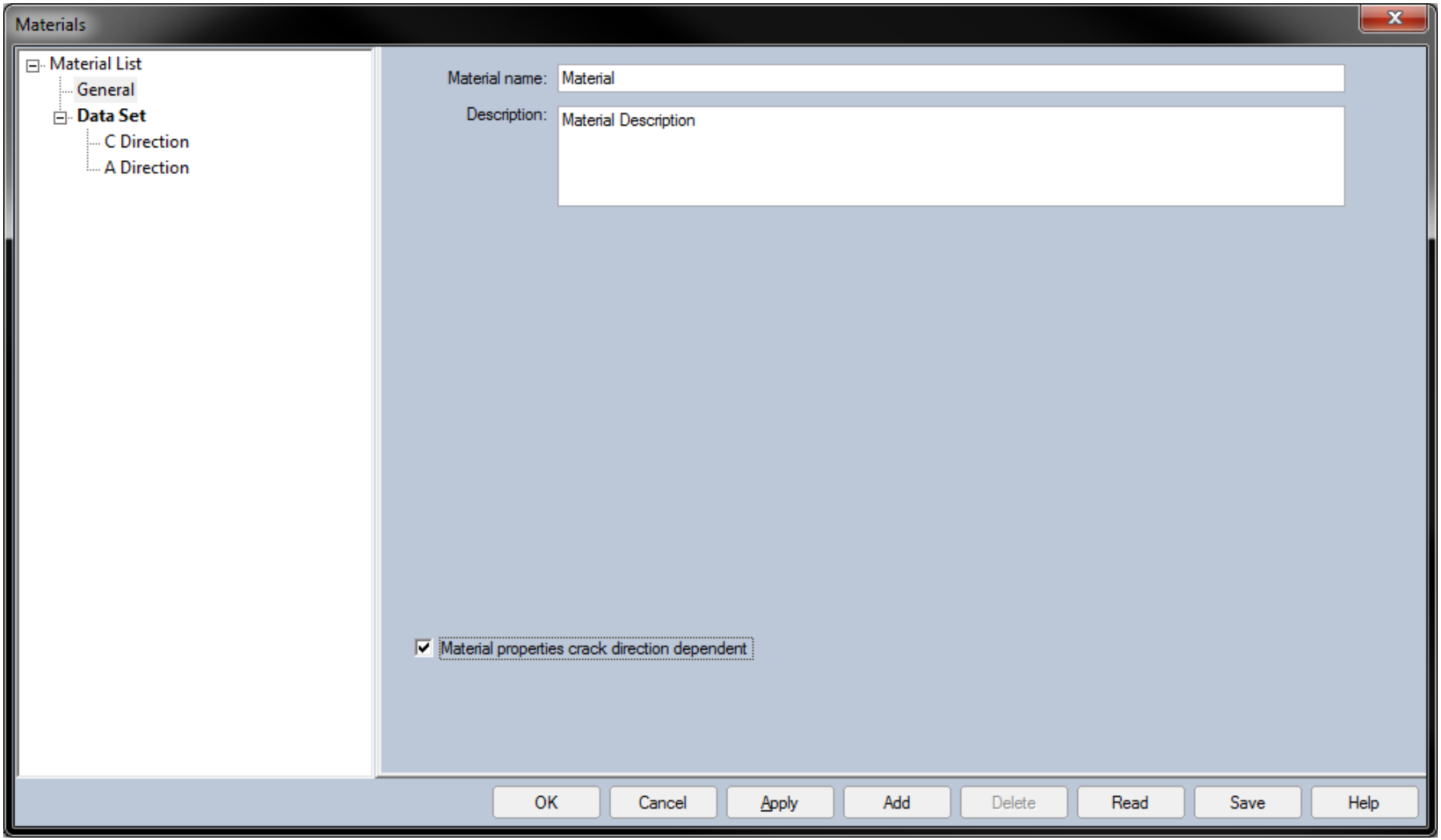
- Obvious differences between L-S and L-T data
  - Possible variation due to forging process
  - Consistent tensile strength

Tensile Testing – Test Method ASTM B557-14						
Specimen	Direction	Initial Diameter (in)	Initial Area (sq. in)	Ultimate Tensile Strength(ksi)	0.2% Offset Yield Strength (ksi)	Elong. 4D (%)
1	Longitudinal	0.249	0.0487	75.2	65.0	12.0
2	Long-Trans	0.249	0.0487	74.7	65.0	11.5
Sample #3	Short-Tans	0.1605	0.0202	75.2	66.4	9.5

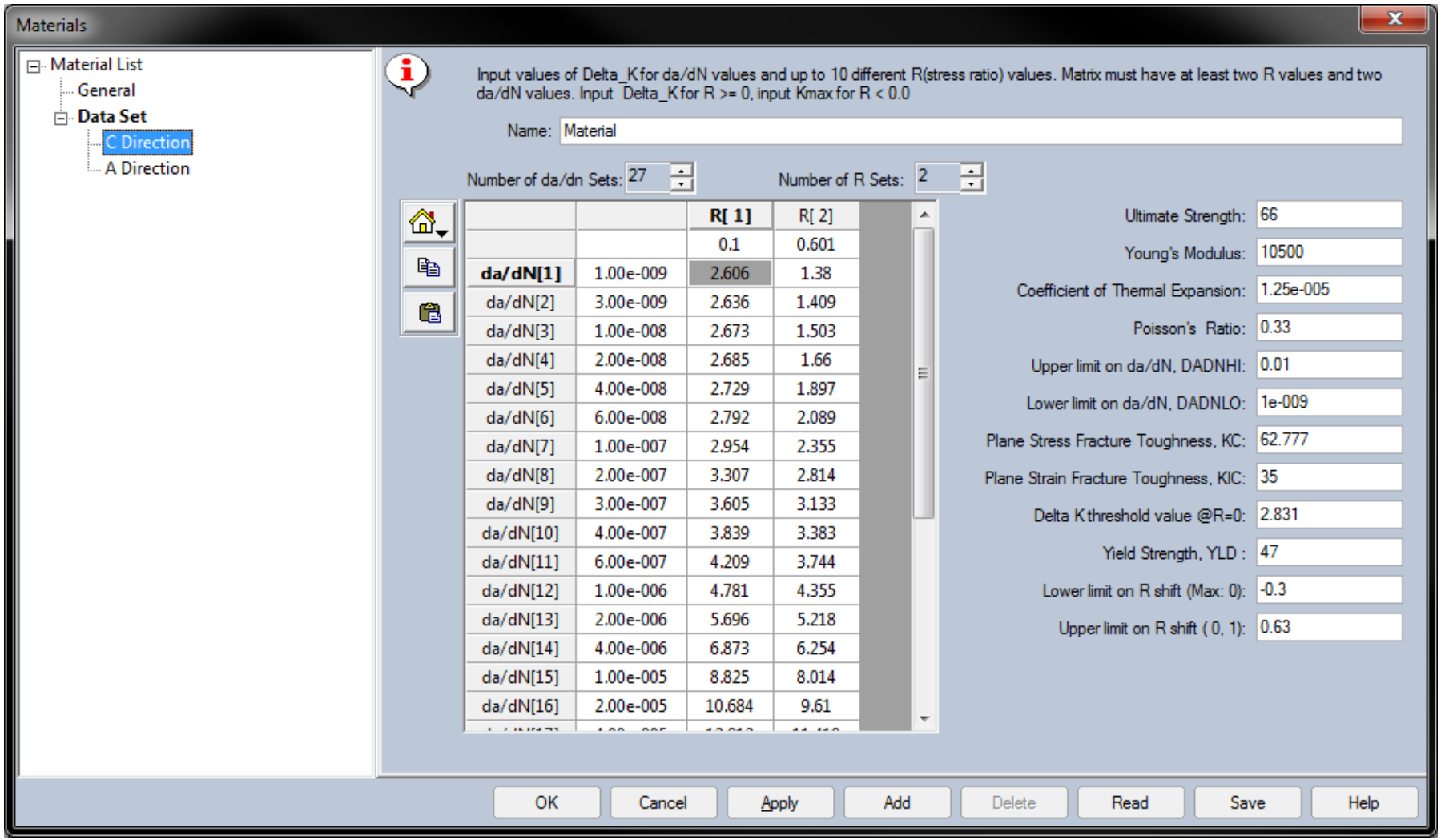
  - Metallographic evaluation in work

New AFGROW Version

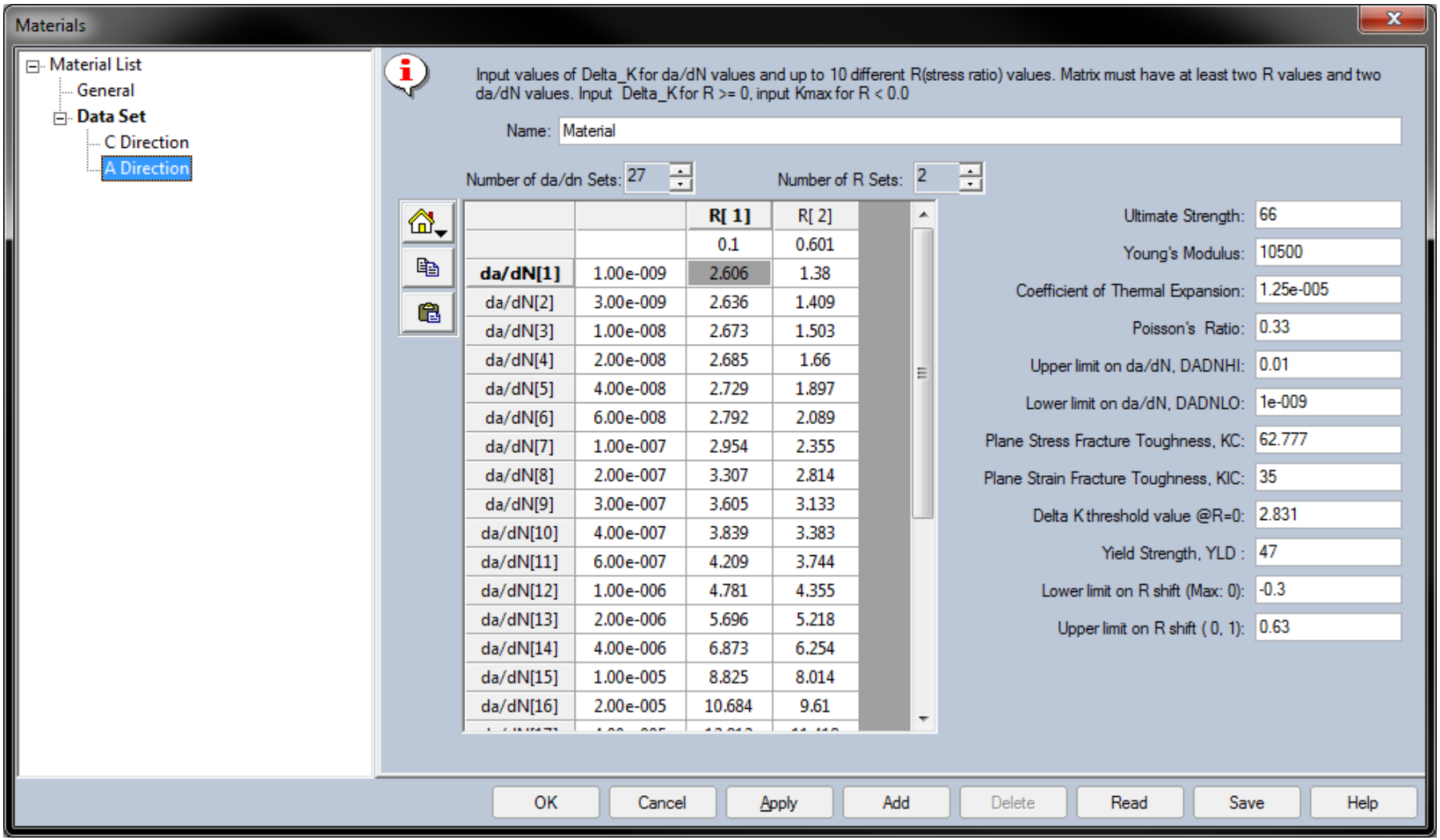
New AFGROW Version: Lookup File Interface



New AFGROW Version: Lookup File Interface



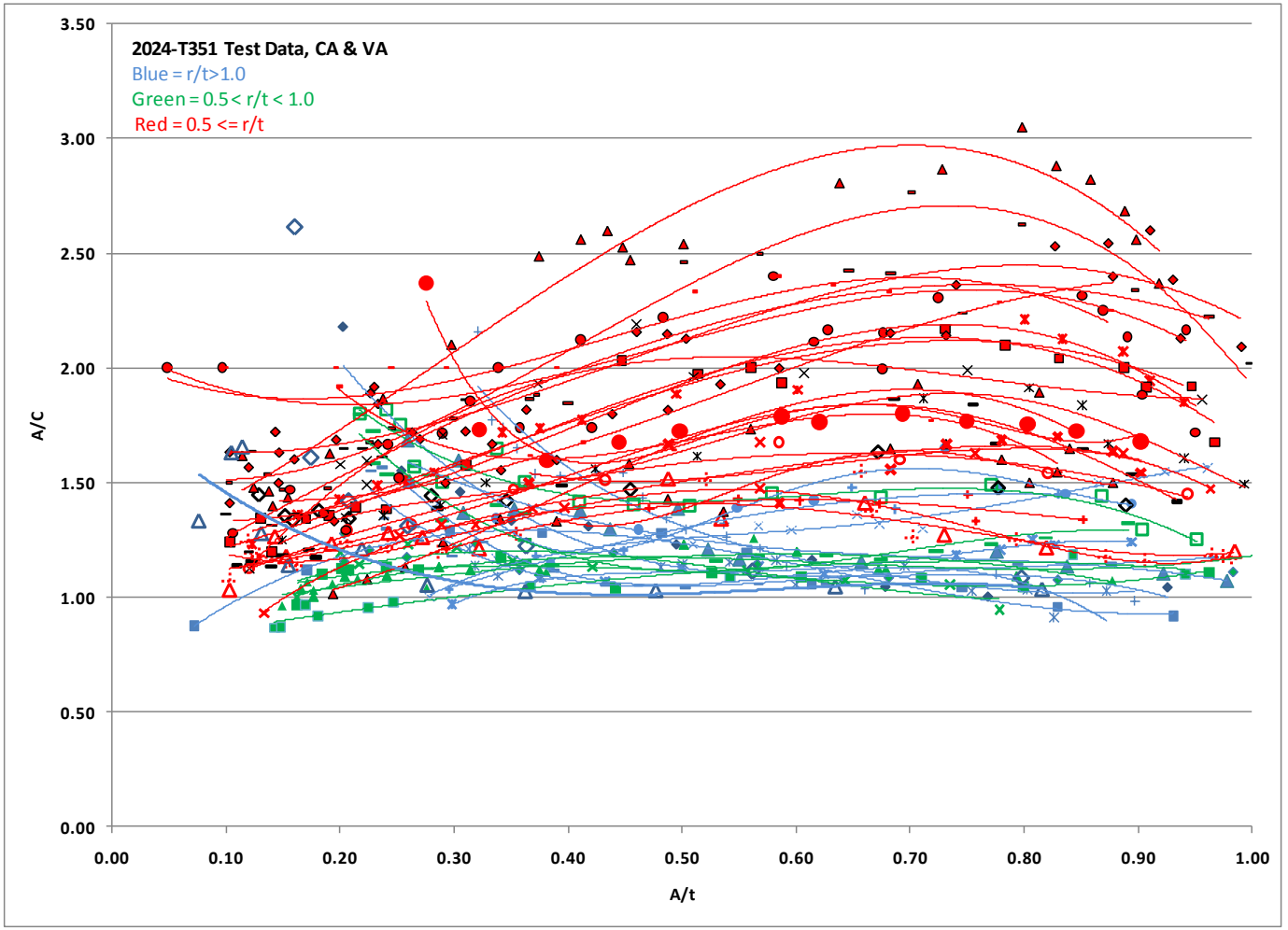
New AFGROW Version: Lookup File Interface



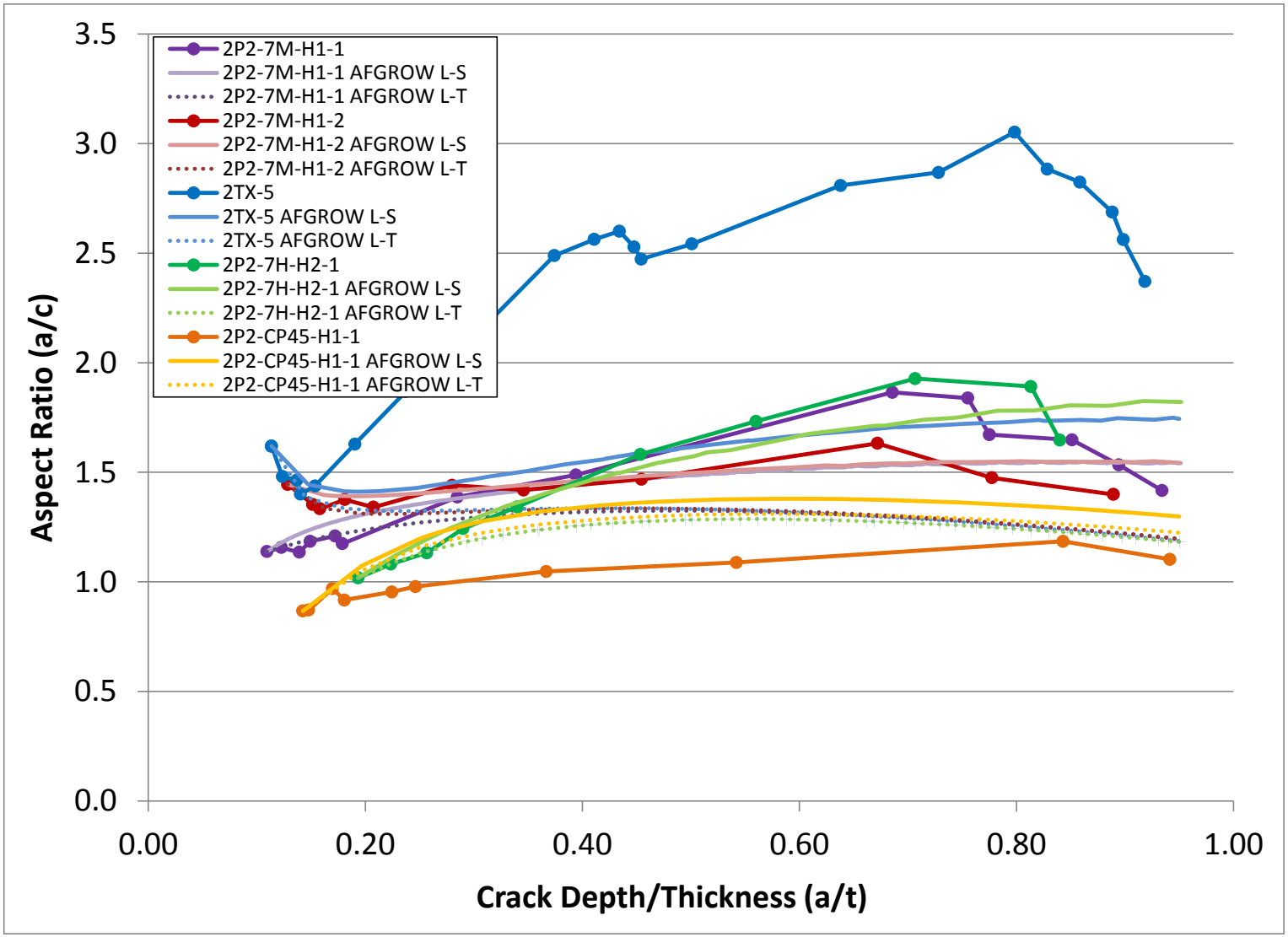
Equilibrium Crack Aspect Ratio, Cont.

(Pilarczyk, 2011)

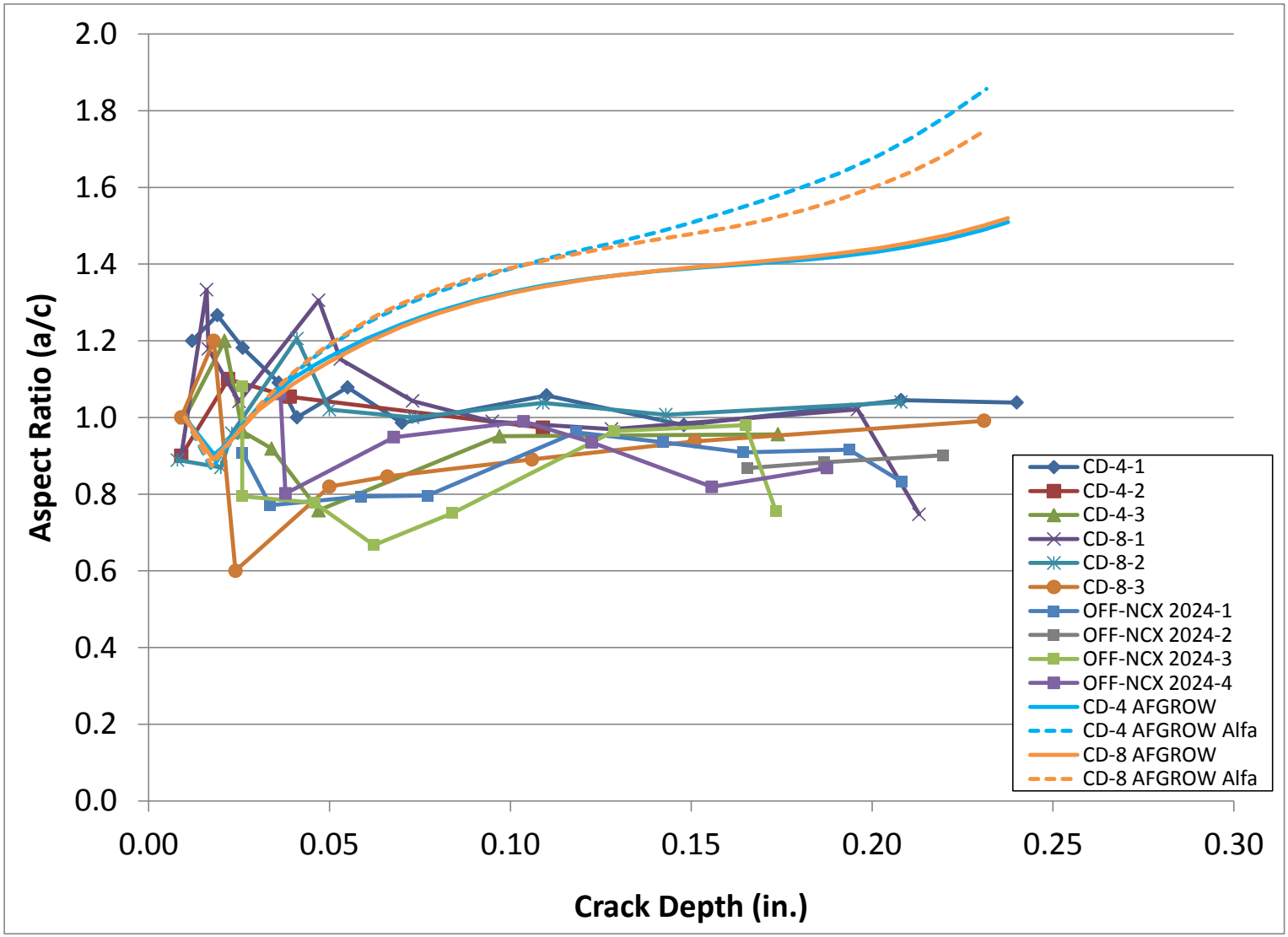
- 2024-T351 Data



Aspect Ratio Comparisons: 2024-T351, VA



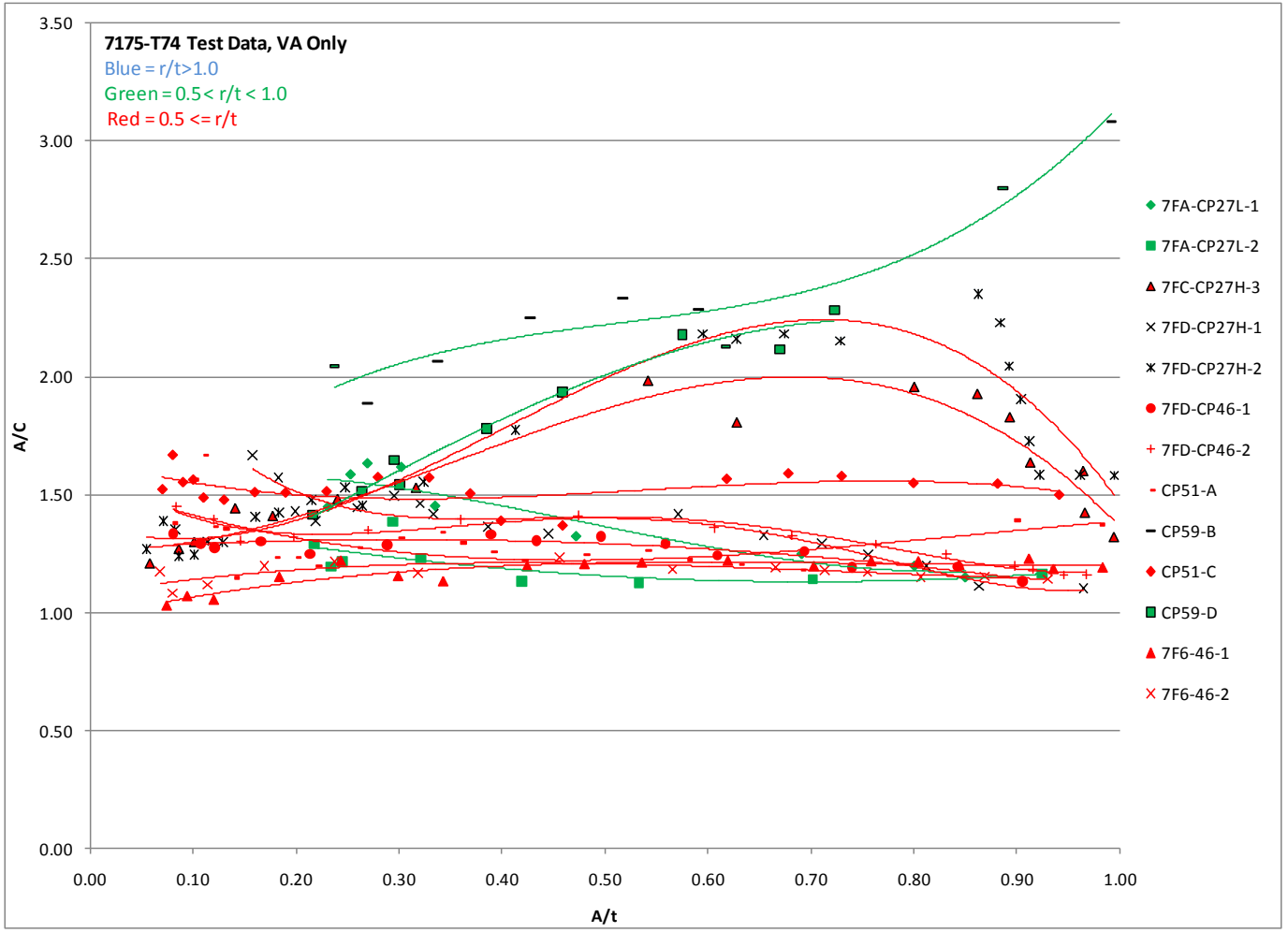
Aspect Ratio Comparisons: 2024-T351, CA



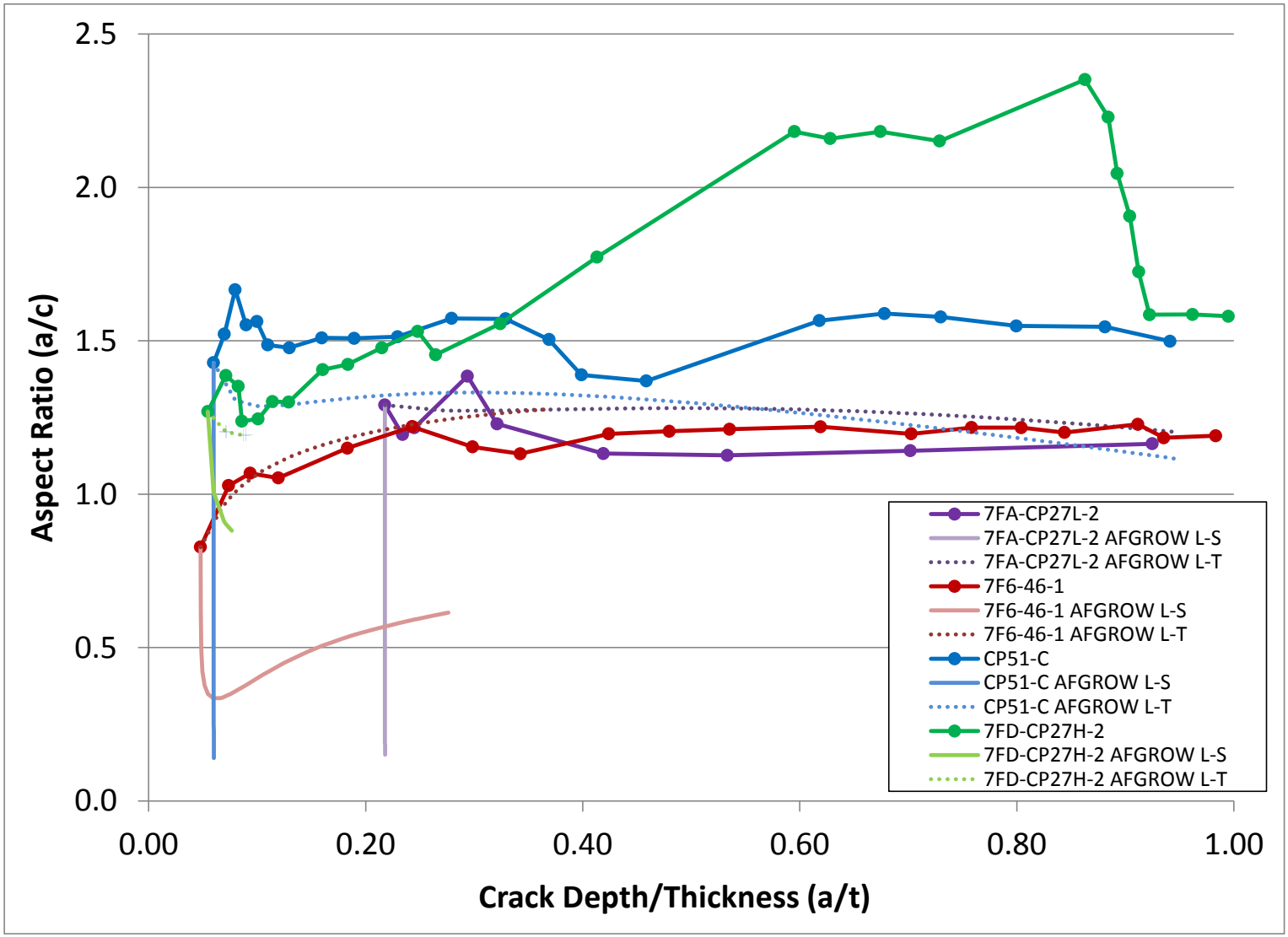
Equilibrium Crack Aspect Ratio, Cont.

(Pilarczyk, 2011)

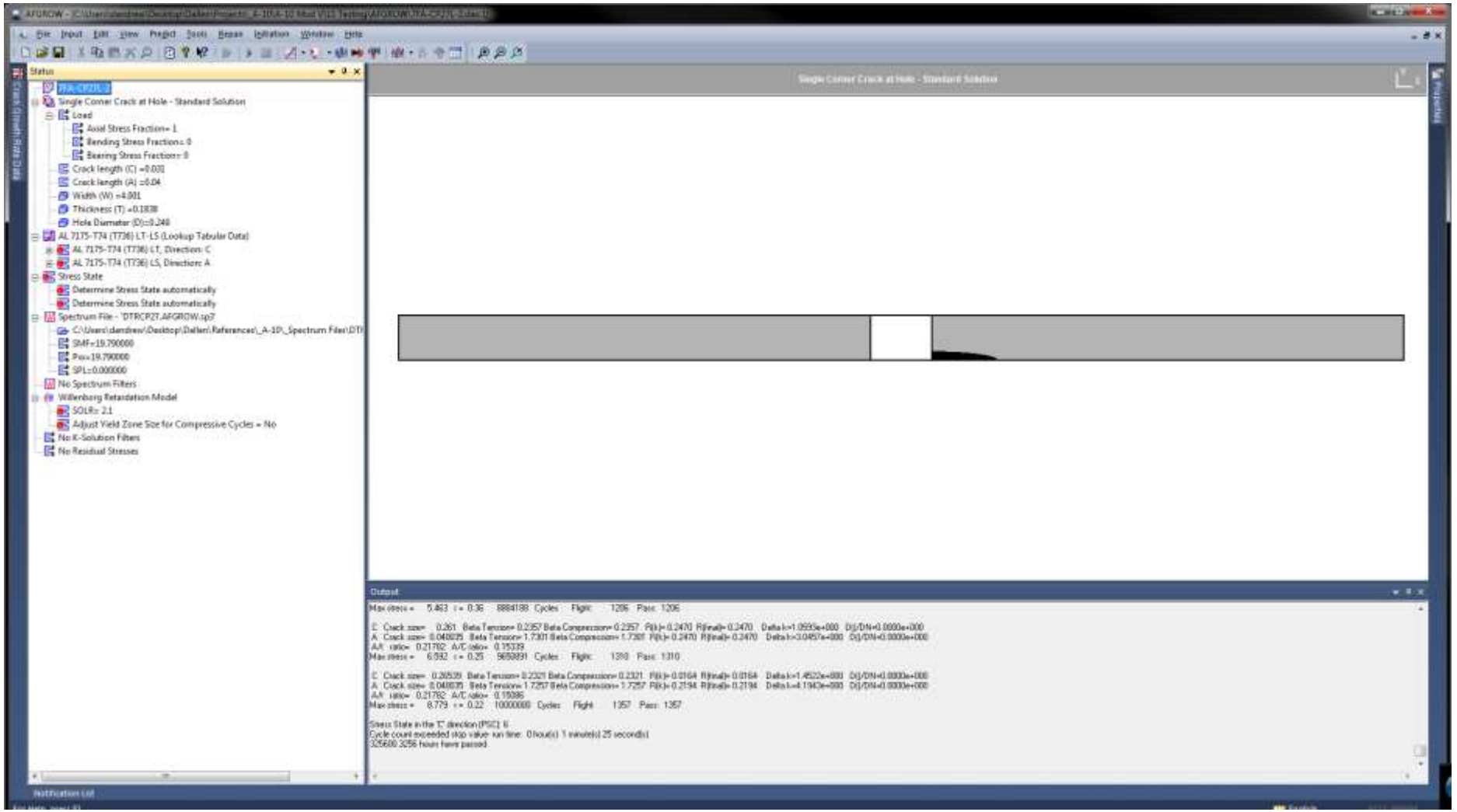
- 7175-T74 Data



Aspect Ratio Comparisons: 7175-T74, VA



Aspect Ratio Comparisons: 7175-T74



Conclusions

- 2024-T351
  - Using L-S data for ‘a’ tip provided a better fit to aspect ratio for VA data – “good”
  - Aspect ratio behavior of CA data seemed non-typical
- 7175-T74
  - Threshold behavior differs drastically from typical/expected
  - Further investigation of FCGR data is warranted – “pretty terrible”

Conclusions: Big Picture Takeaway

- Expected to see differences between L-S and L-T growth, especially more in the forging than in the plate
- Variability in the test aspect ratio seemed to be more significant than we can predict with the L-S growth rates in our analyses
- The forging issues preclude us from making any real conclusions as to whether L-S growth rates will improve analyses

Conclusions: What next?

- Investigation comparing coupon-to-coupon variation against magnitude of our inaccuracy to see which is more significant
- Aspect ratio/SOLR correlation with BAMF and new AFGROW using L-S and L-T data
- Bore crack lengths (DTM)
  - Possible visual investigation
  - May require quantitative fractography to determine
- Additional thoughts?
  - Additional L-S material testing?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