

AFGROW User Workshop 2015

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

SOUTHWEST RESEARCH INSTITUTE®

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the public through innovative science
and technology*

- **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 \neq Constant**
 - **What are the Impacts???**
 - **Recent Studies Indicate A/C \neq Constant Over-Predicting Bore Crack Growth (Classic AFGROW Model (a@80deg, c@5deg))**
- **This Presentation Evaluates Impacts from Changing A/C \neq Constant**





Comparison to Constant Amplitude Data

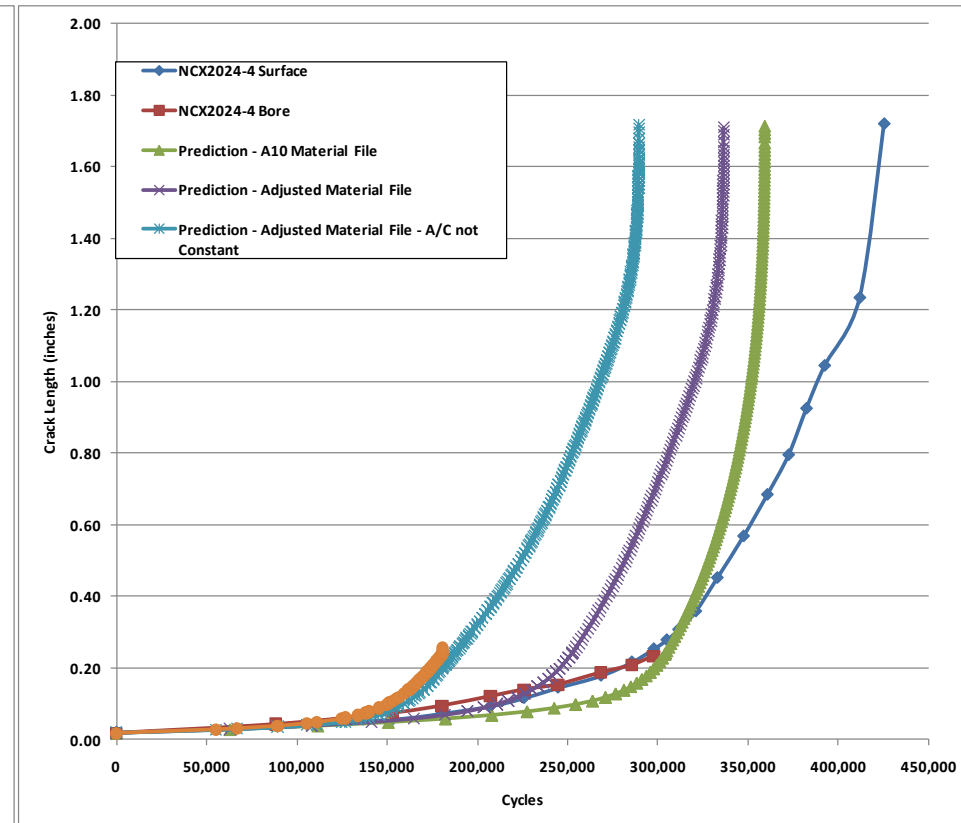
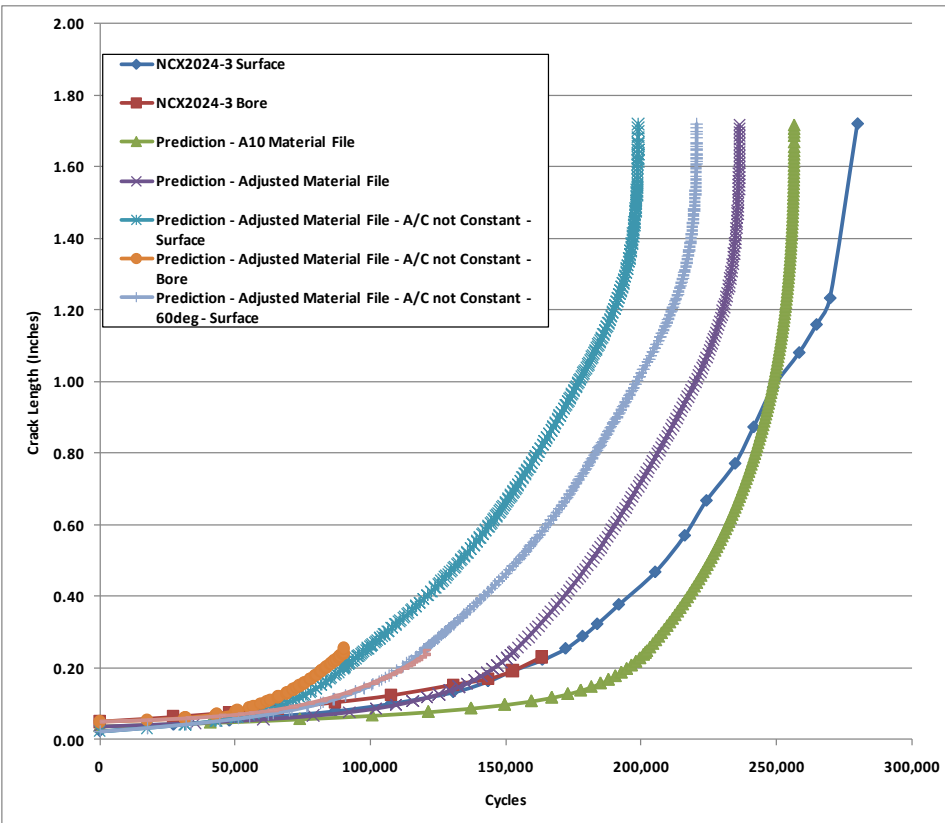
(Pilarczyk, 2011)

■ Carlson/Pilarczyk Theses

- A/C Constant, Avg. IFS Predicts 82% of Tested Life
- A/C \neq 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

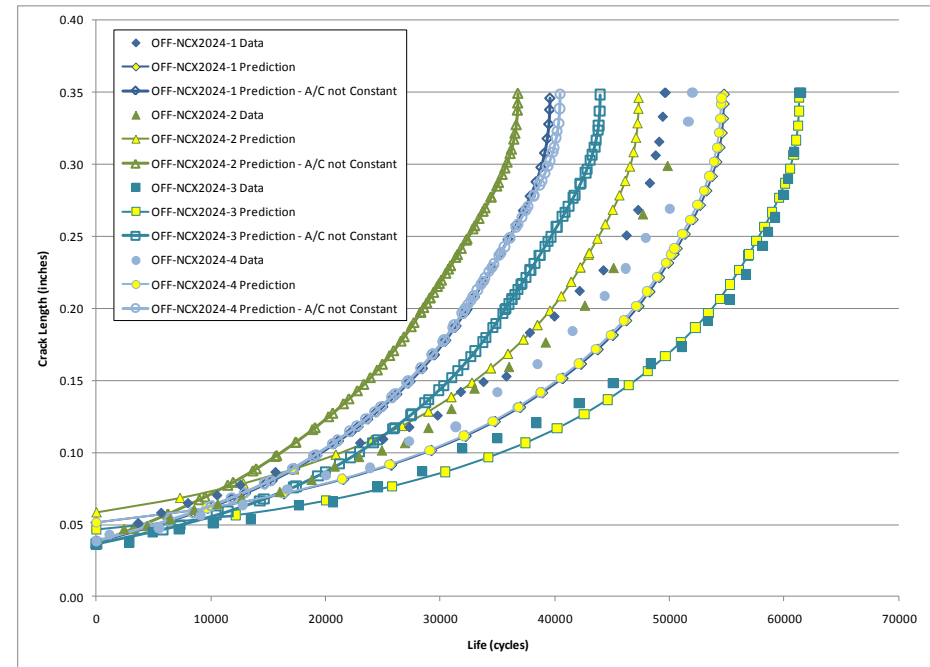
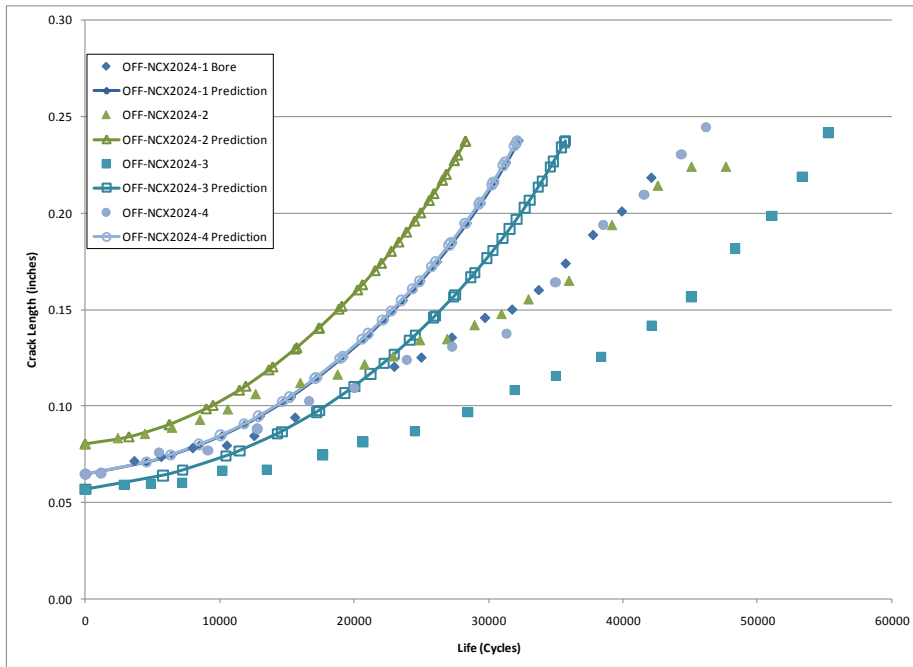
(Pilarczyk, 2011)

■ Andrew/Warner Theses

- A/C Constant, Avg. IFS Predicts 101.6% of Tested Life
- A/C \neq 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

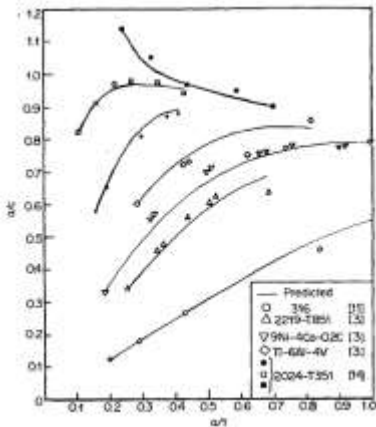


* Avg. IFS for A/C Constant Predictions

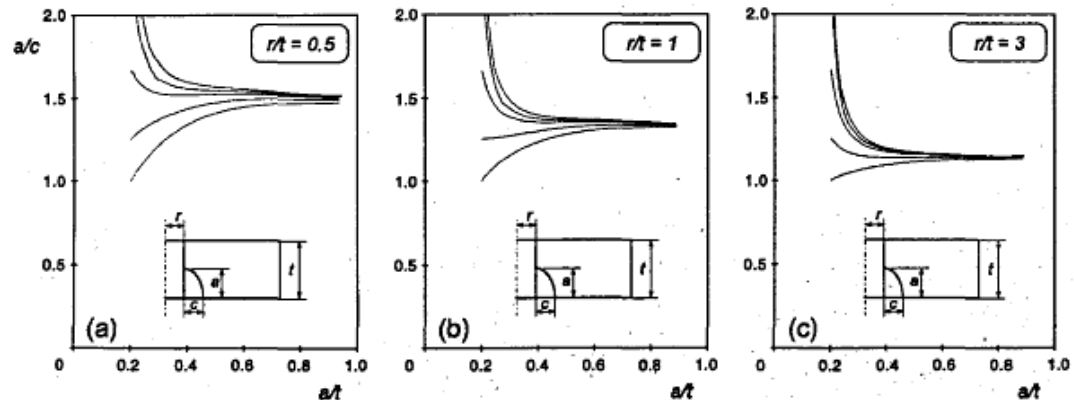
Equilibrium Crack Aspect Ratio

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.

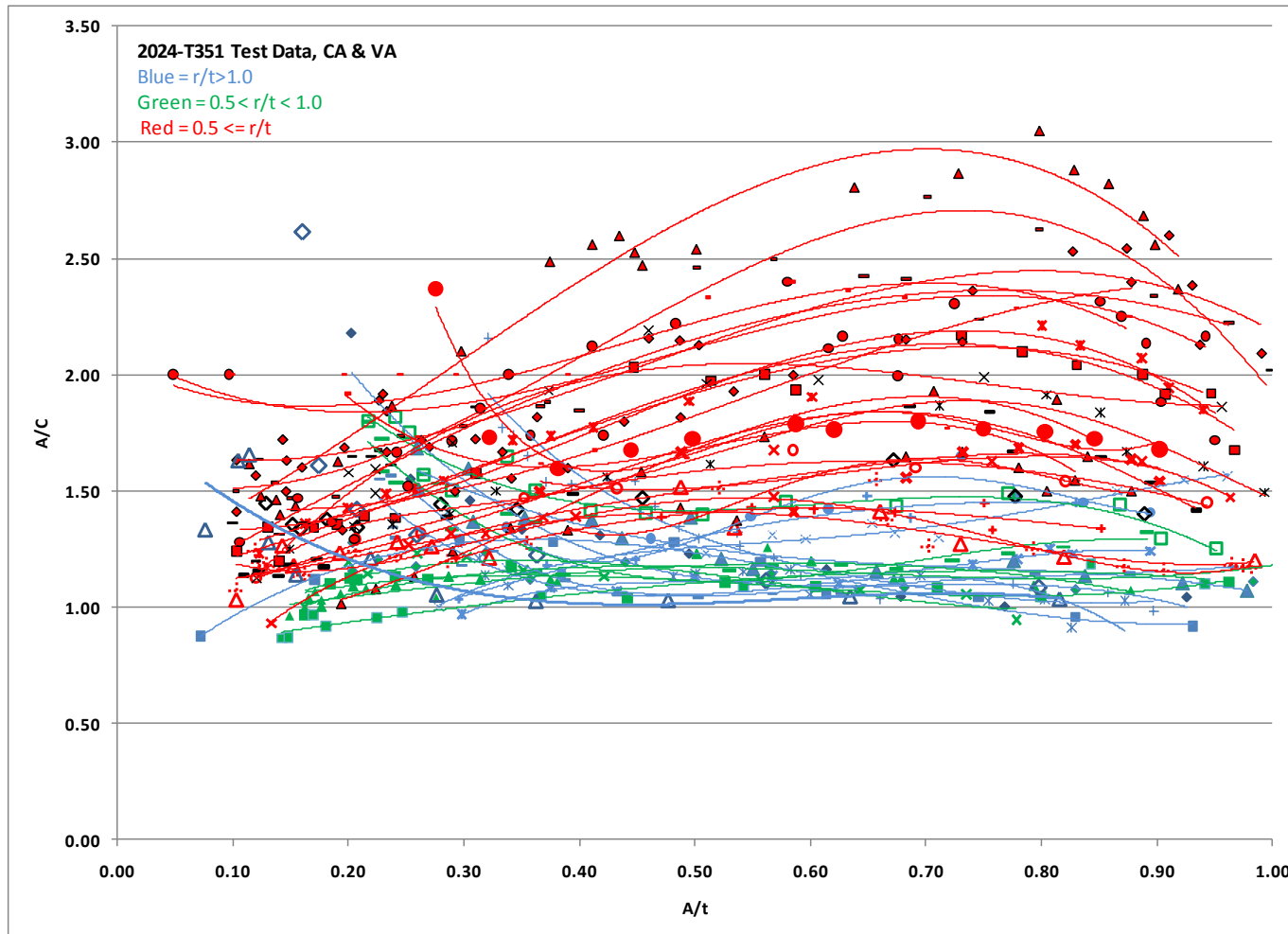
Ref 3: Seog Oh, C., Park, P., Hak Huh, Y., Gyu Ko, S., Young Hwang, D., Mo An, H. (2005). Fatigue Crack Growth Behavior of Corner Cracks under LBH Loading. Key Engng Mater. 297-300, 128-134.

Equilibrium Crack Aspect Ratio, Cont.



(Pilarczyk, 2011)

2024-T351 Data

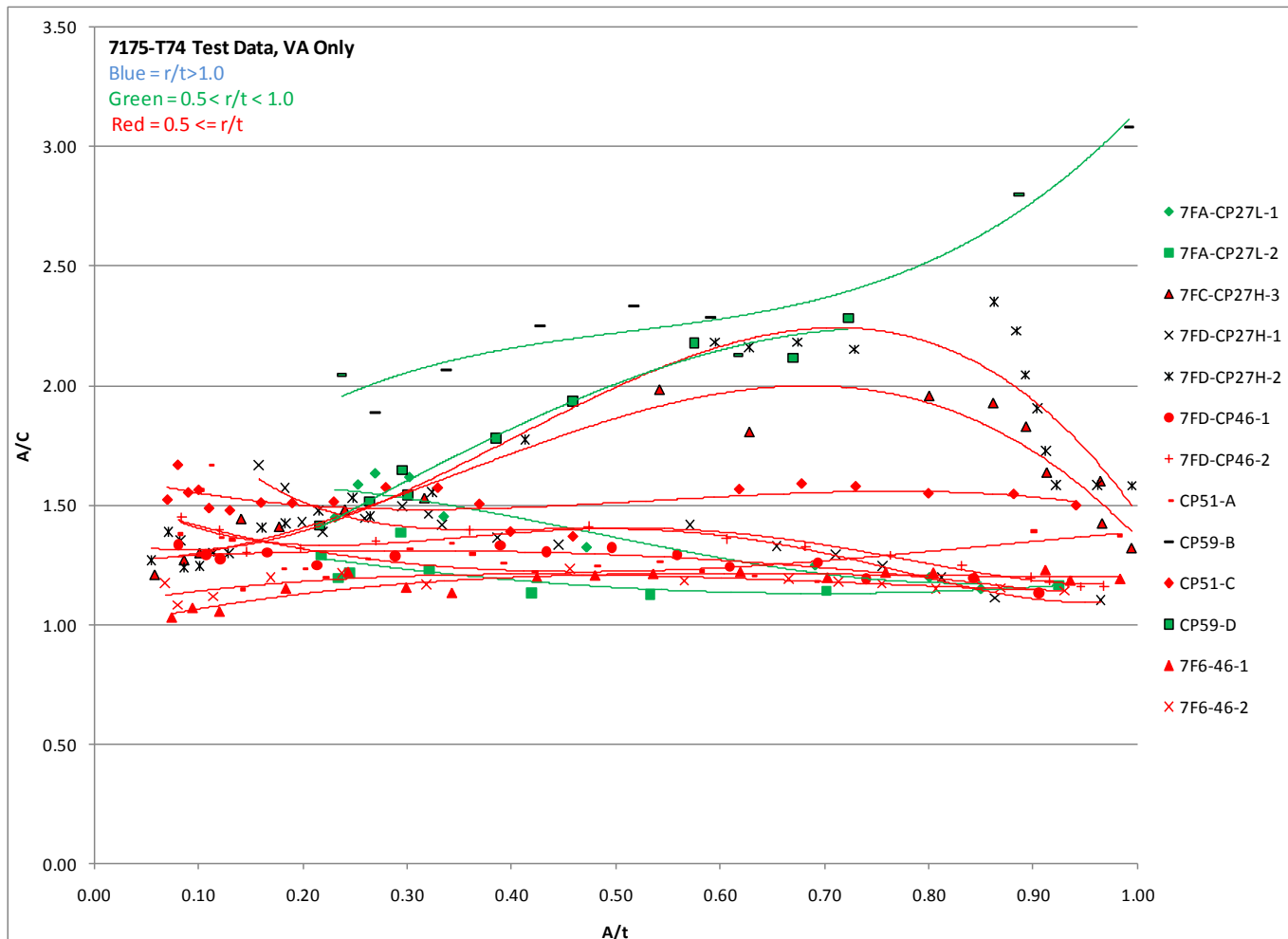


Equilibrium Crack Aspect Ratio, Cont.



(Pilarczyk, 2011)

7175-T74 Data



■ Going Forward

- **If $A/C = \text{Constant}$, What Should be the IFS for SOLR Correlation Given that $A \neq C$ 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.**

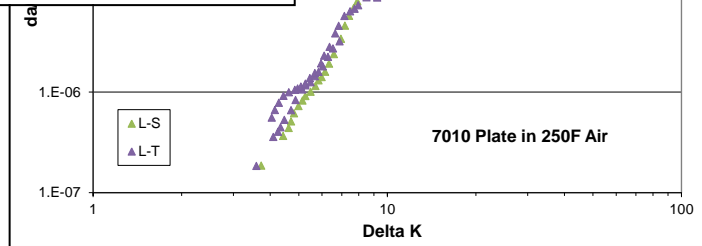
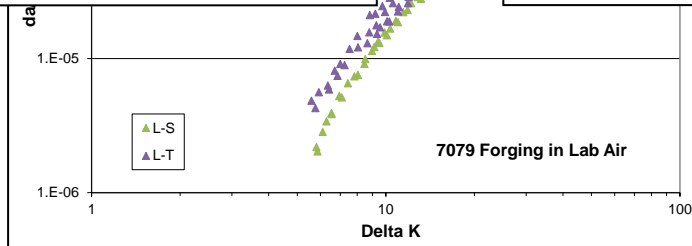
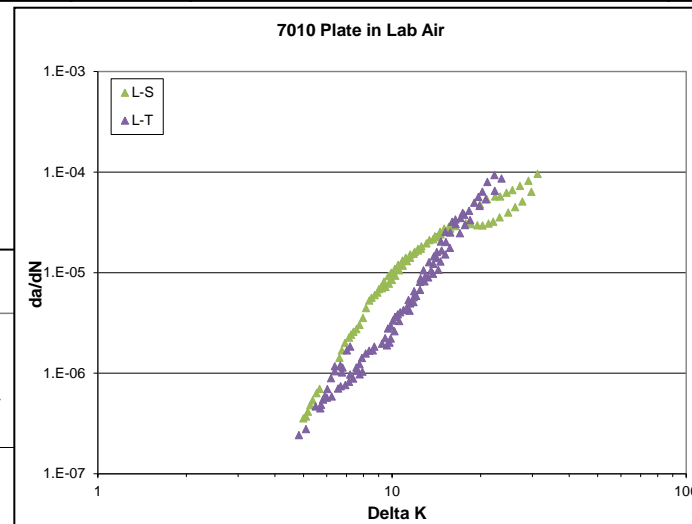
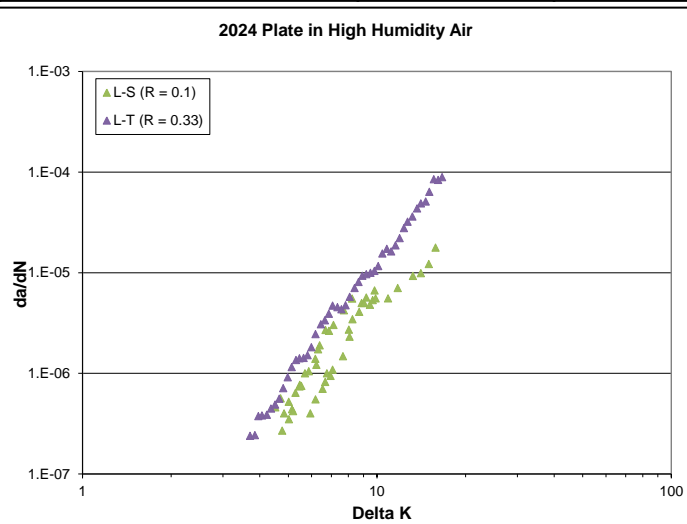
Test Type	Material	Orientation	Geometry	Loading	Specimens
FCGR	2024-T351	L-S	ESE(T)	0.1, 0.5	6
FCGR	7175-T74	L-S	ESE(T)	0.1, 0.5	6





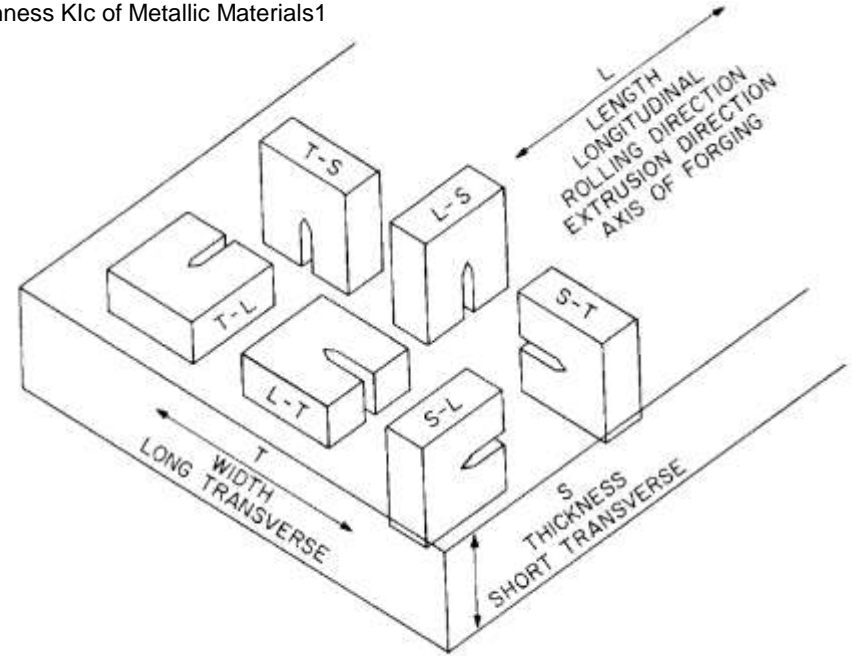
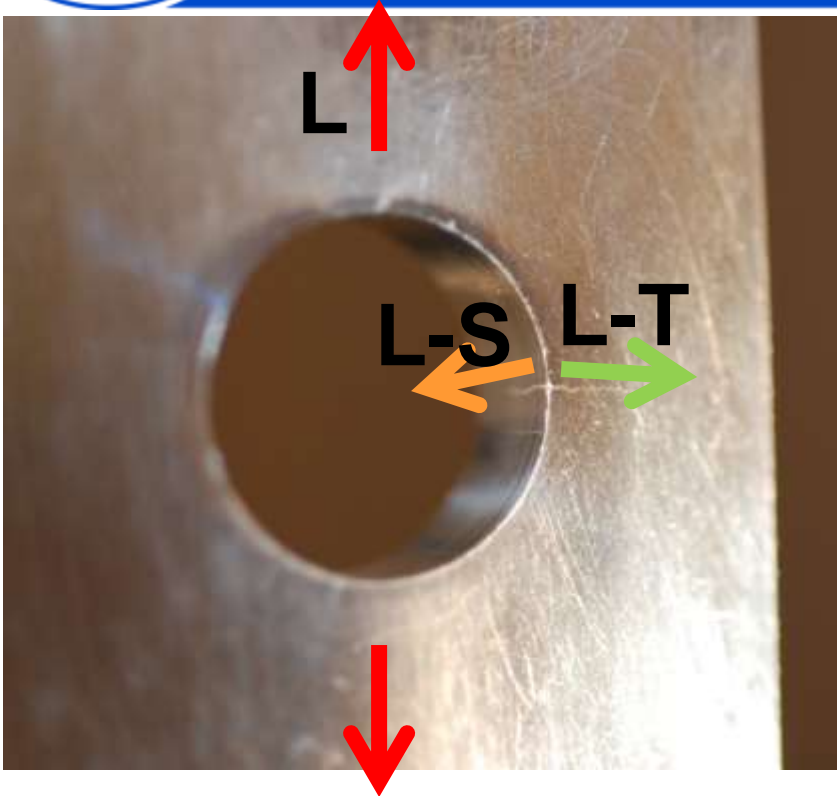
NASMAT Data

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

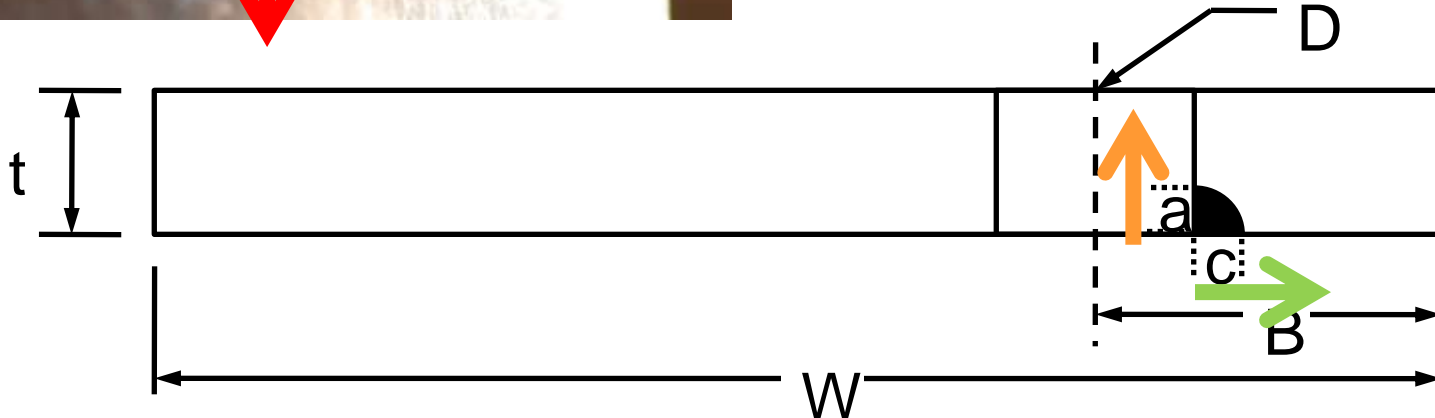


FCGR L-S Testing: Definition of L-S

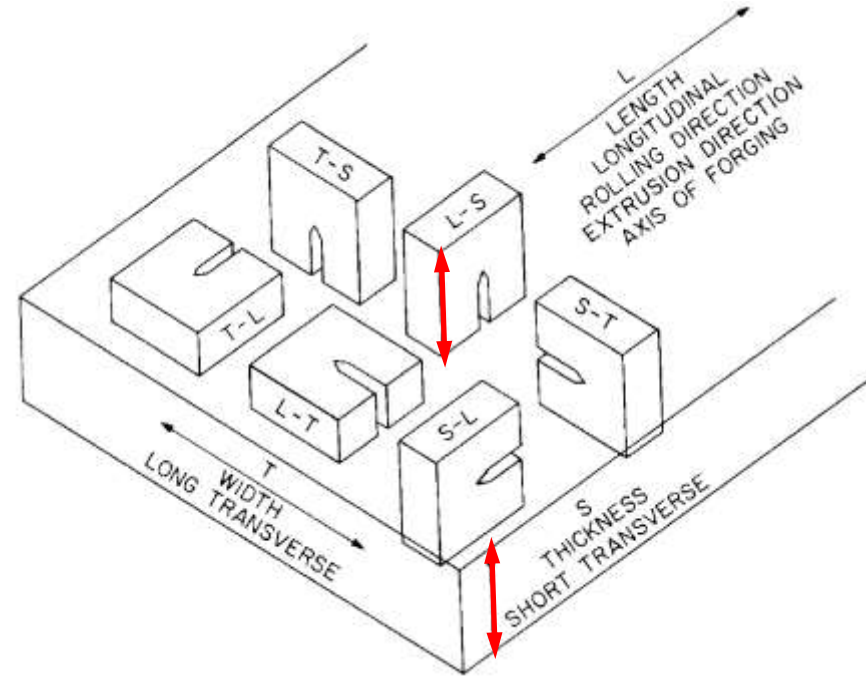
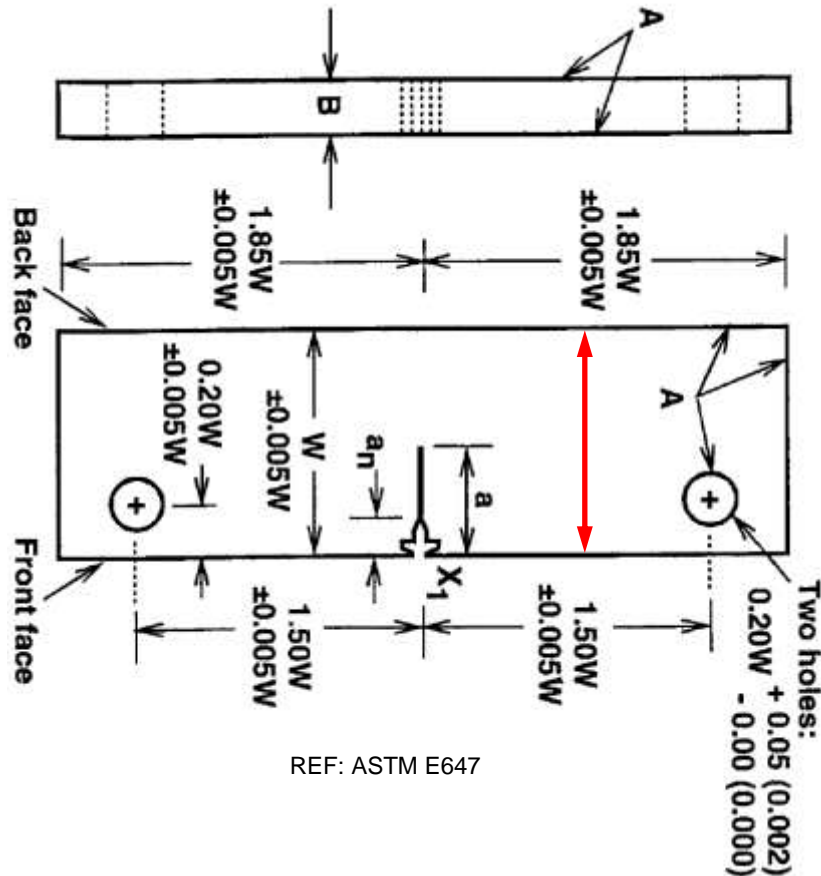
REF: ASTM E399 Standard Test Method for Linear-Elastic Plane-Strain Fracture Toughness K_{Ic} of Metallic Materials¹



(a) Rectangular Sections—Specimens Aligned with Reference Directions



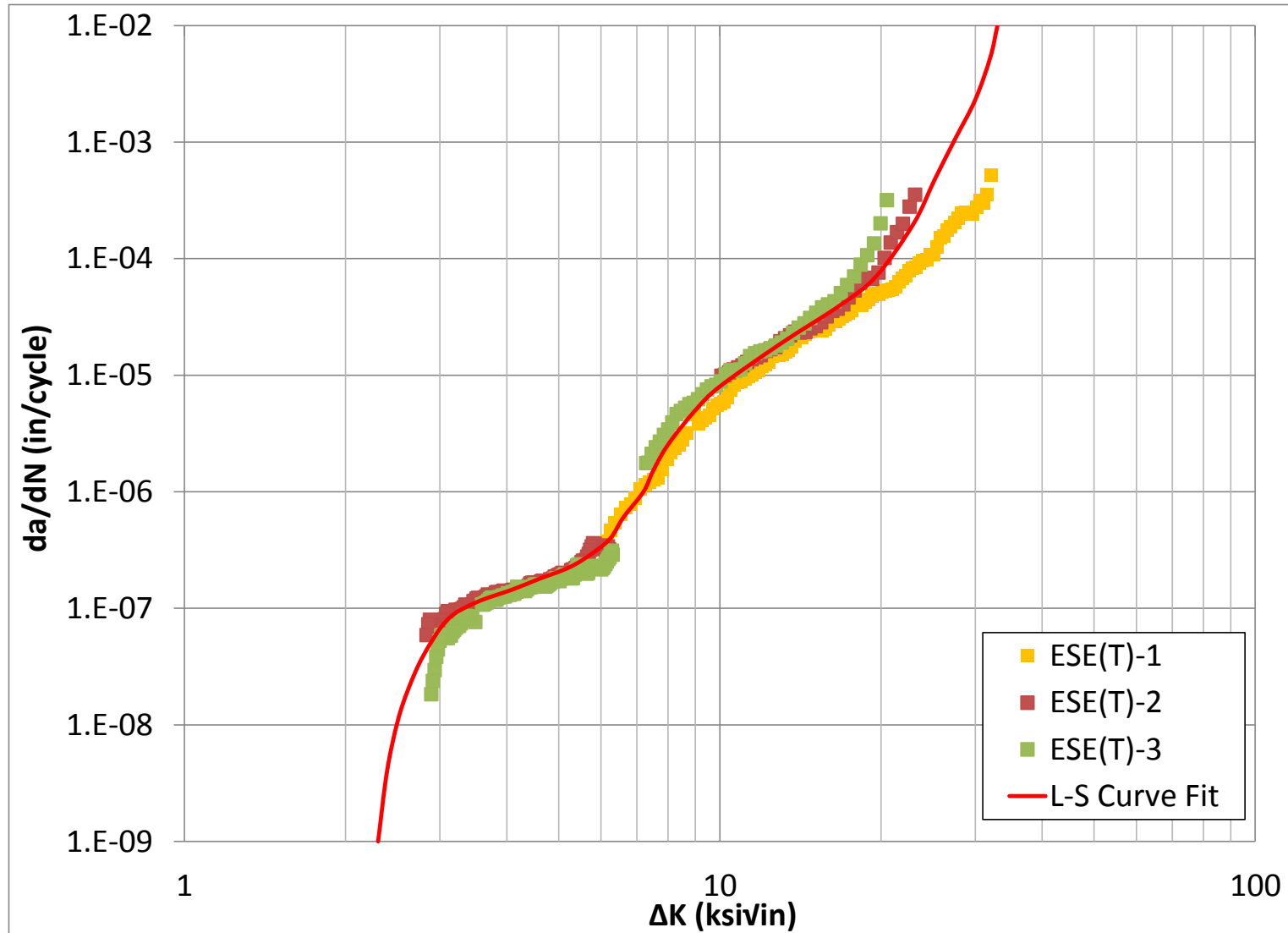
FCGR L-S Testing: Coupon type selection



ESE(T):
THE ECCENTRICALLY-LOADED SINGLE
EDGE CRACK TENSION SPECIMEN

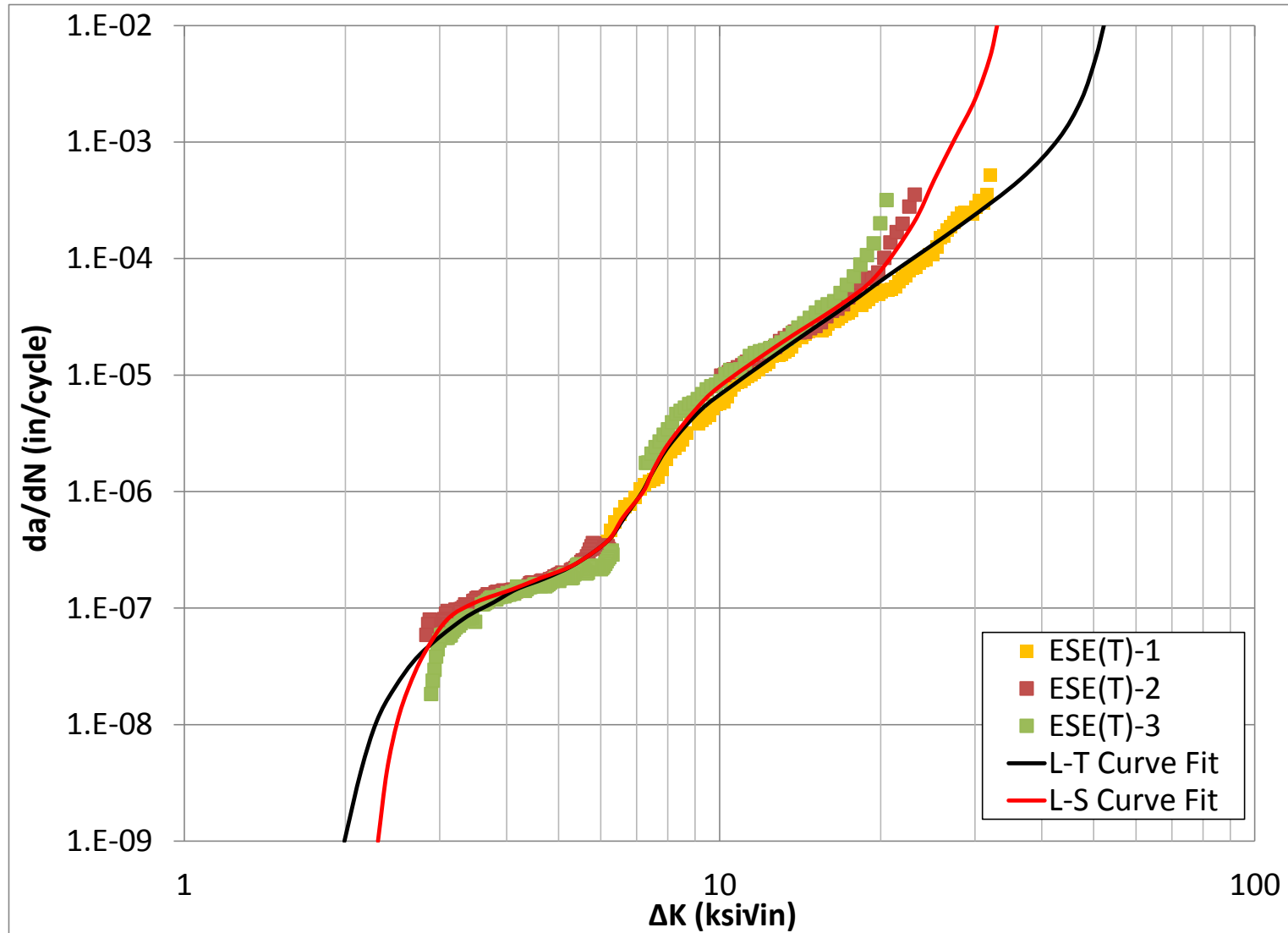


Curve Fit of Test Data: 2024-T351 | R=0.1

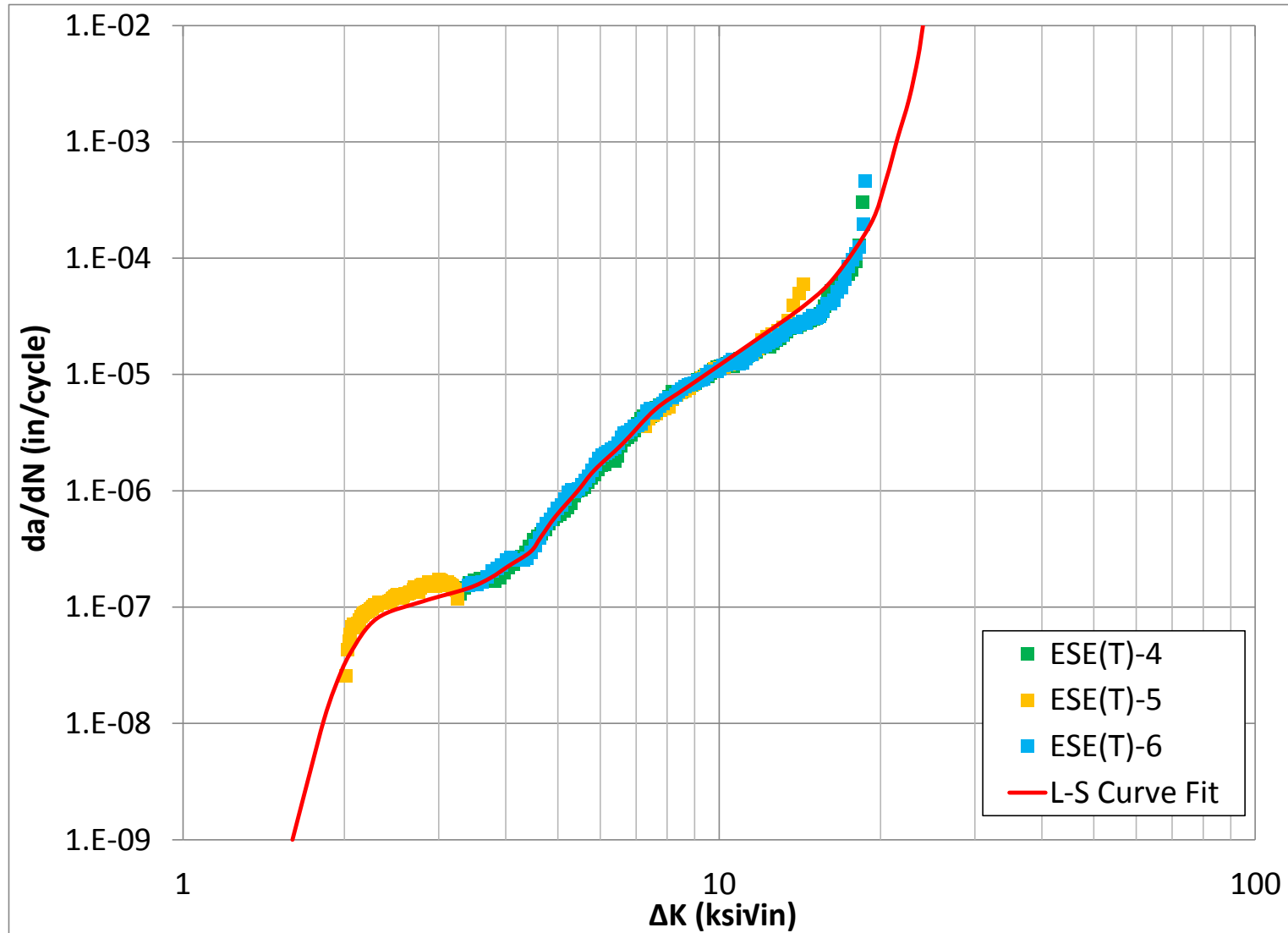




Curve Fit of Test Data: 2024-T351 | R=0.1

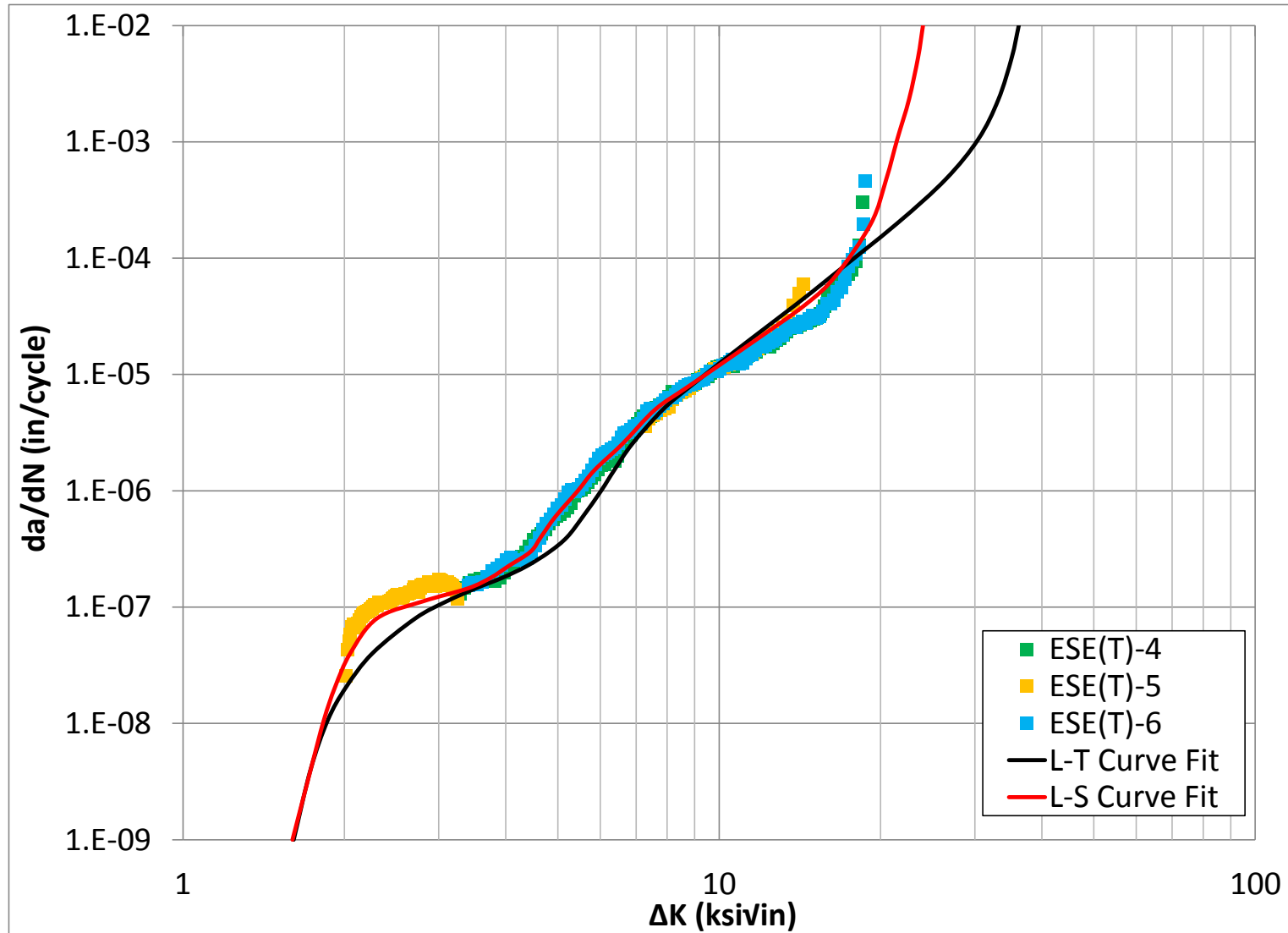


Curve Fit of Test Data: 2024-T351 | R=0.5



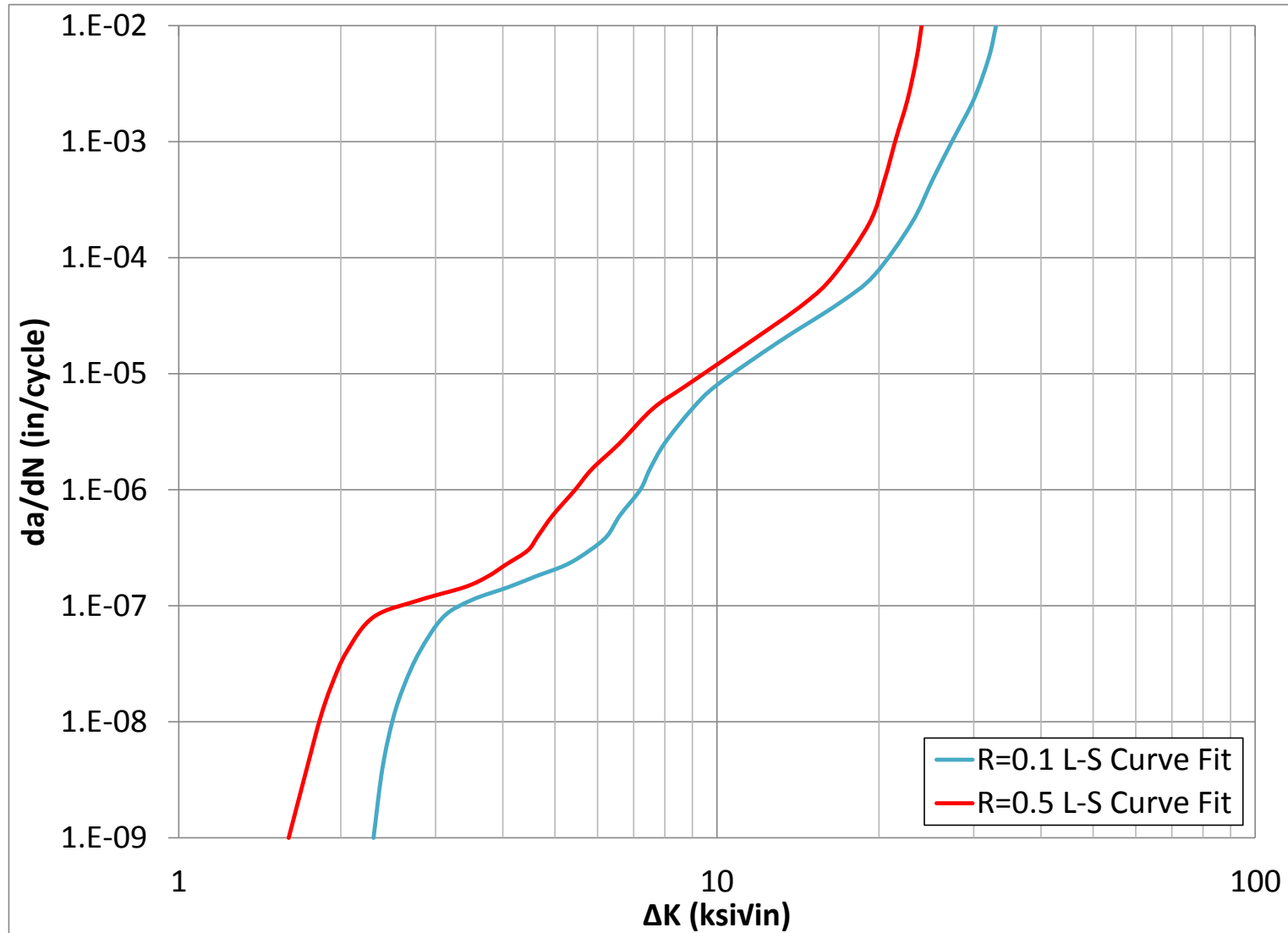


Curve Fit of Test Data: 2024-T351 | R=0.5



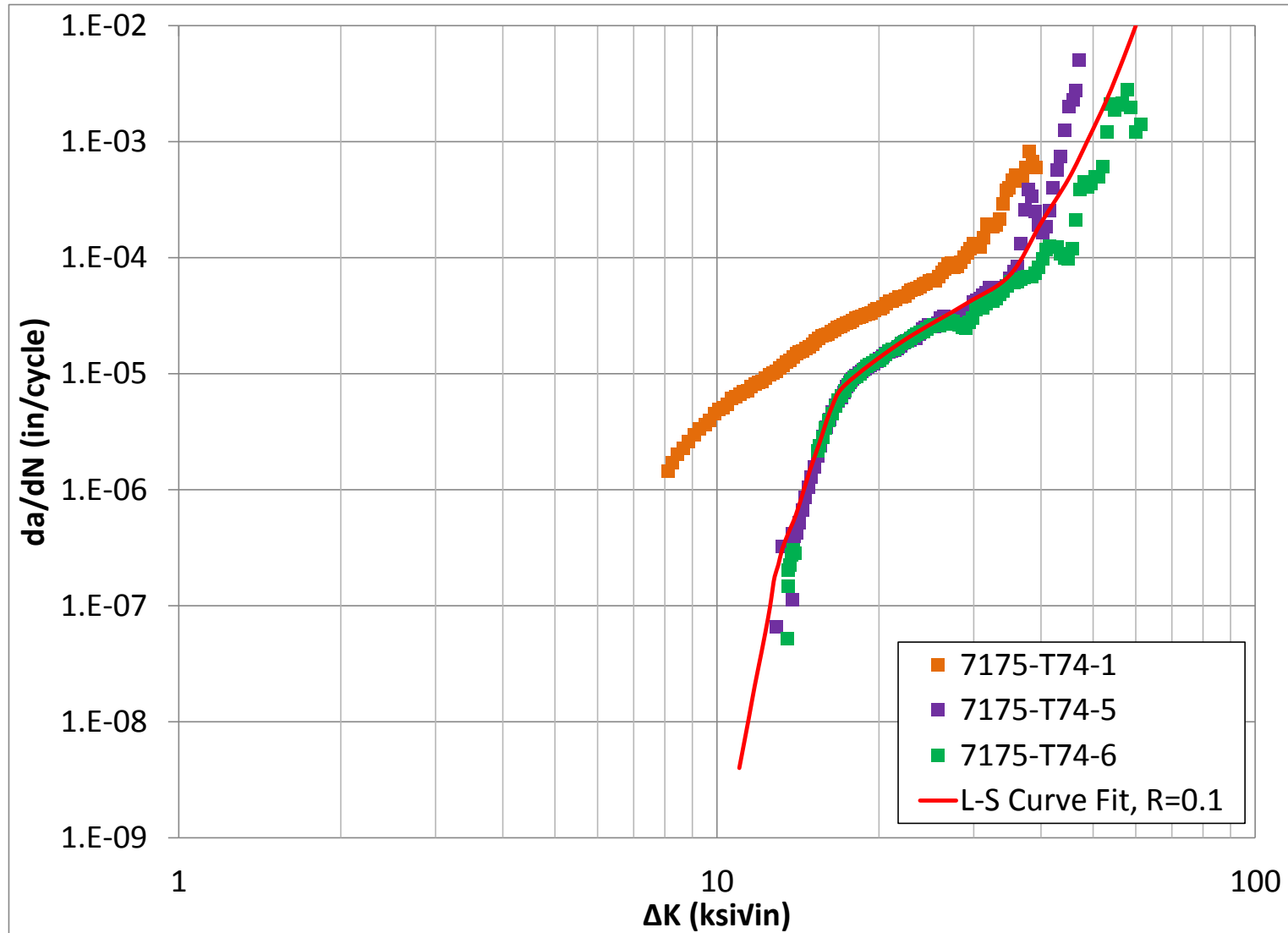


Curve Fit of Test Data: 2024-T351



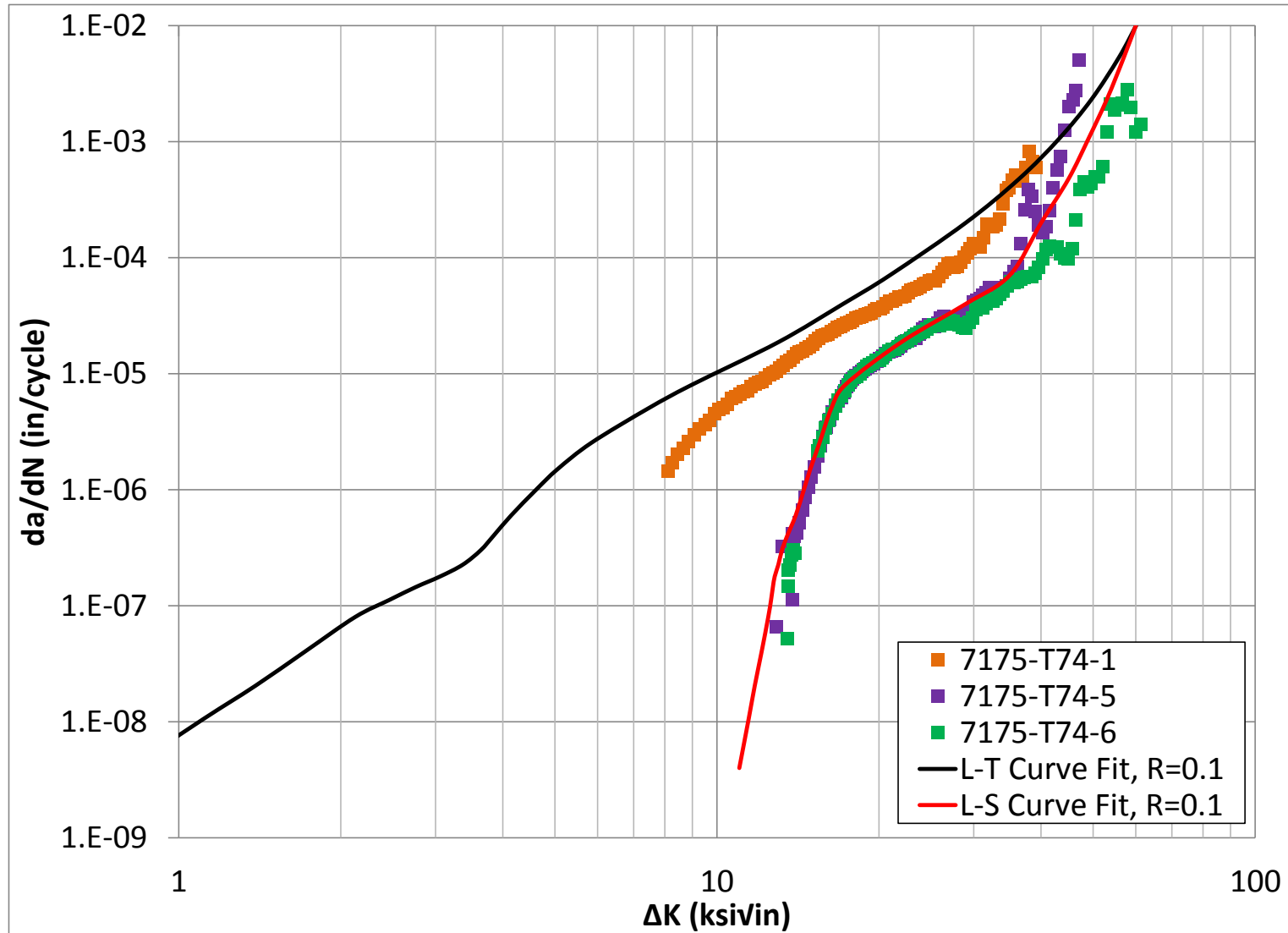


Curve Fit of Test Data: 7175-T74 | R=0.1



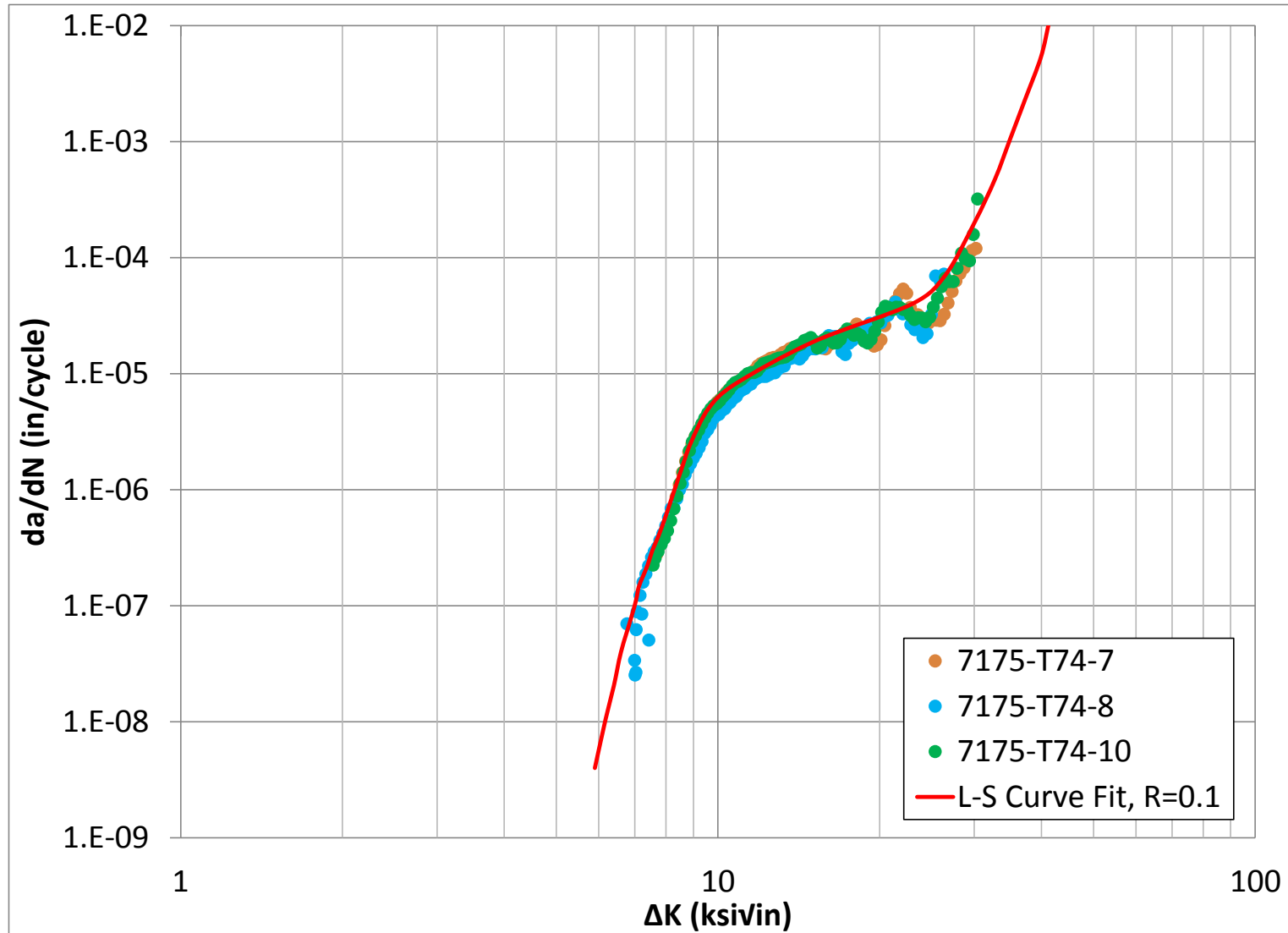


Curve Fit of Test Data: 7175-T74 | R=0.1



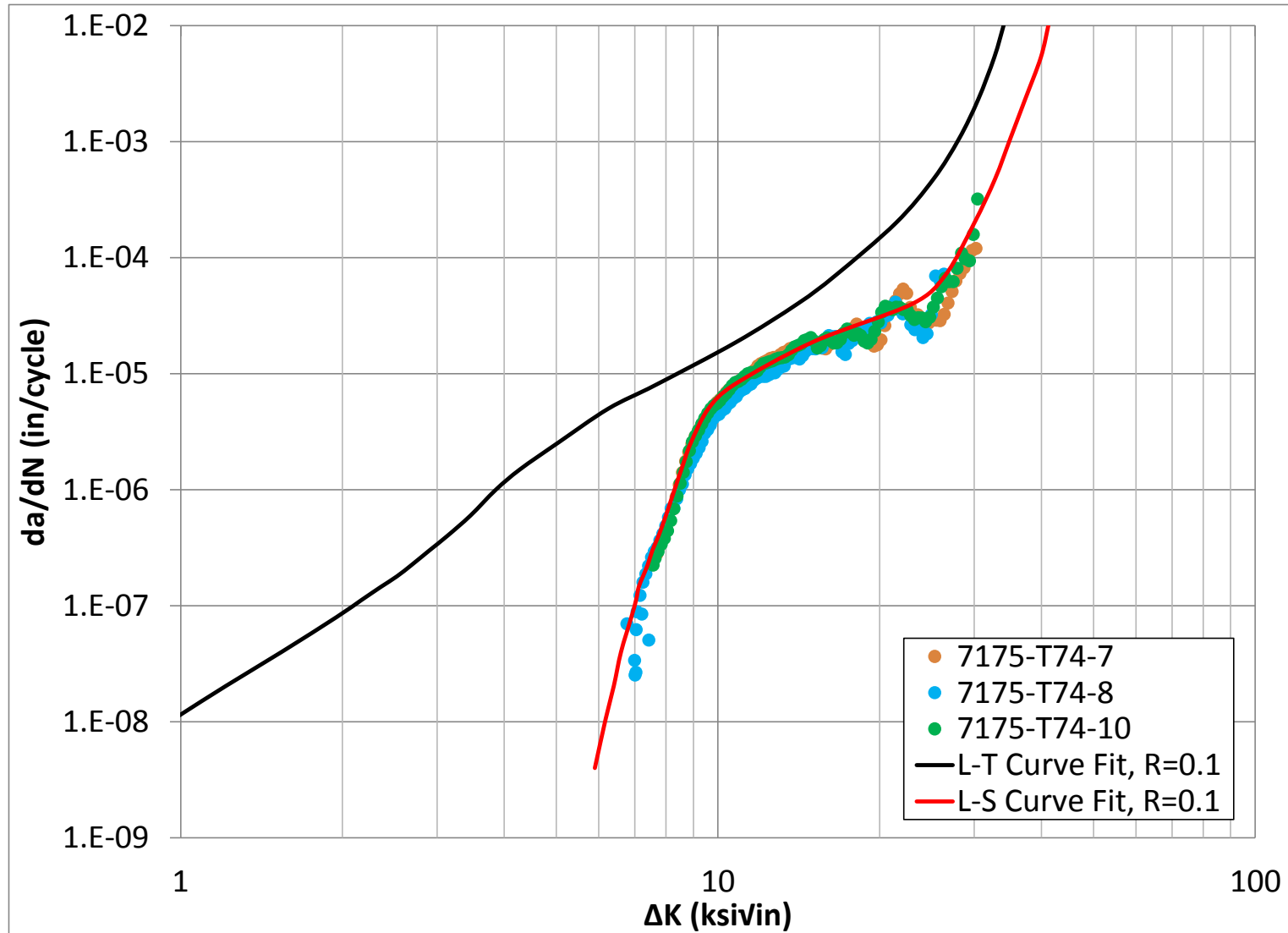


Curve Fit of Test Data: 7175-T74 | R=0.5



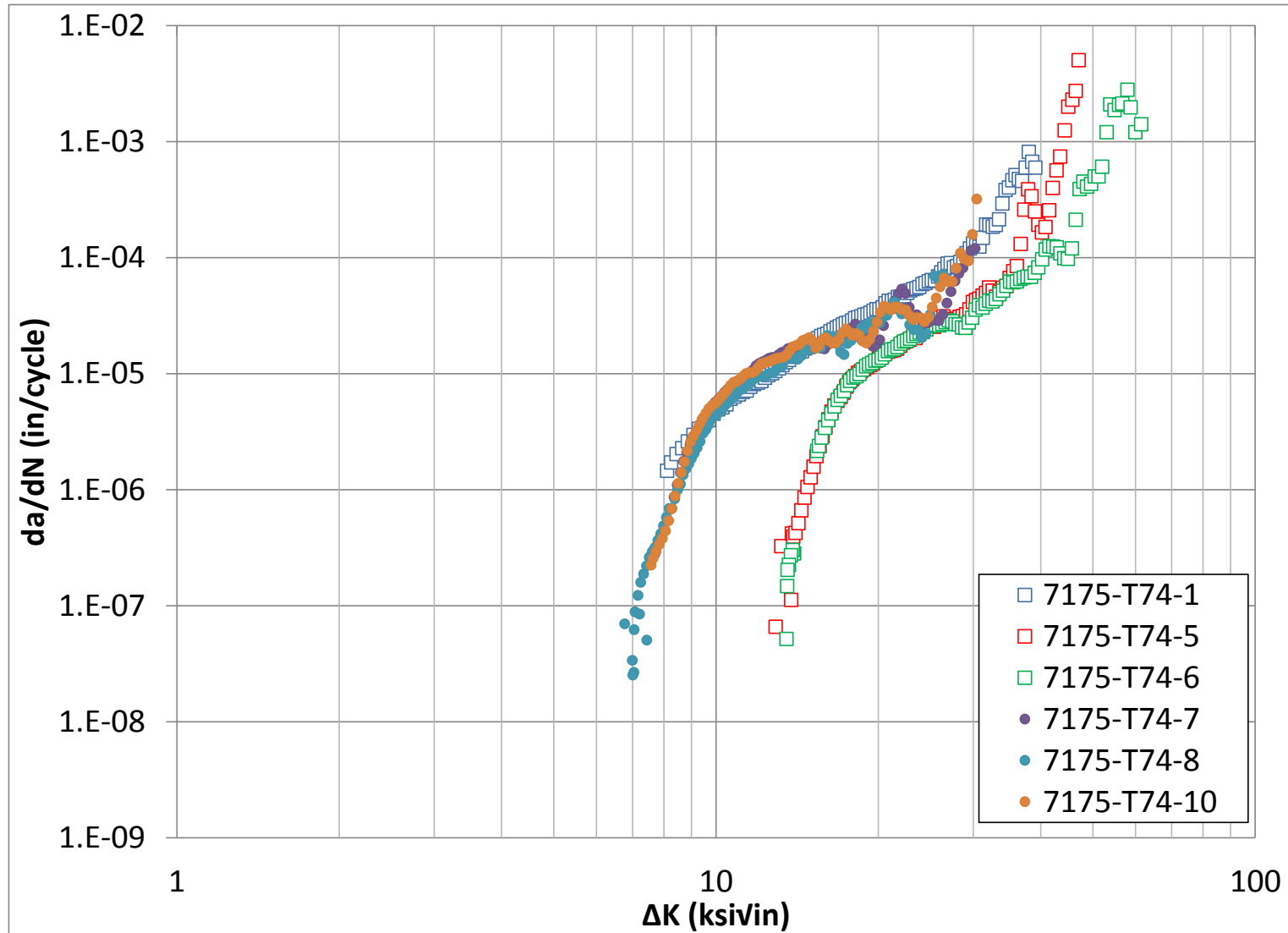


Curve Fit of Test Data: 7175-T74 | R=0.5



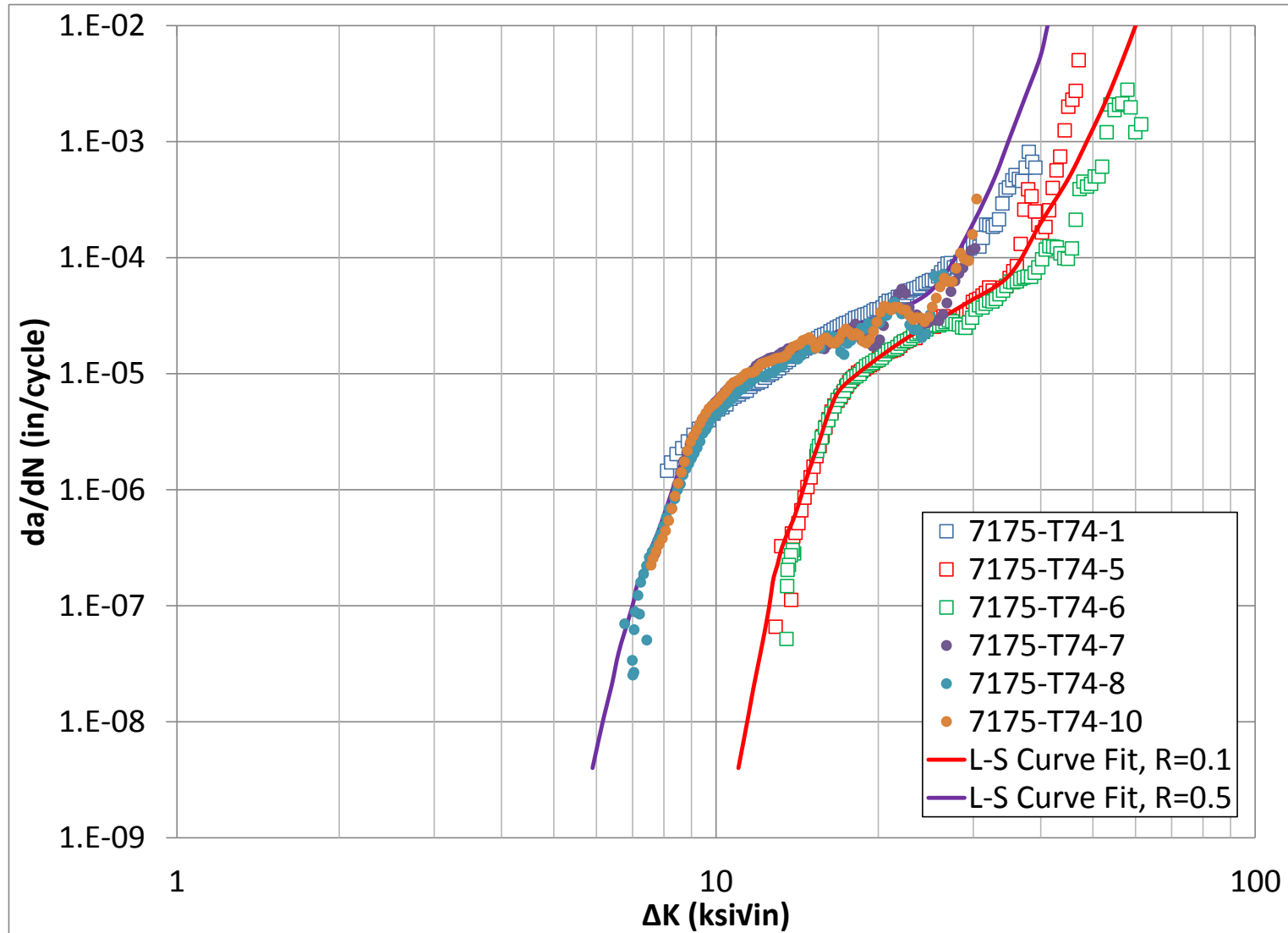


Curve Fit of Test Data: 7175-T74 | L-S



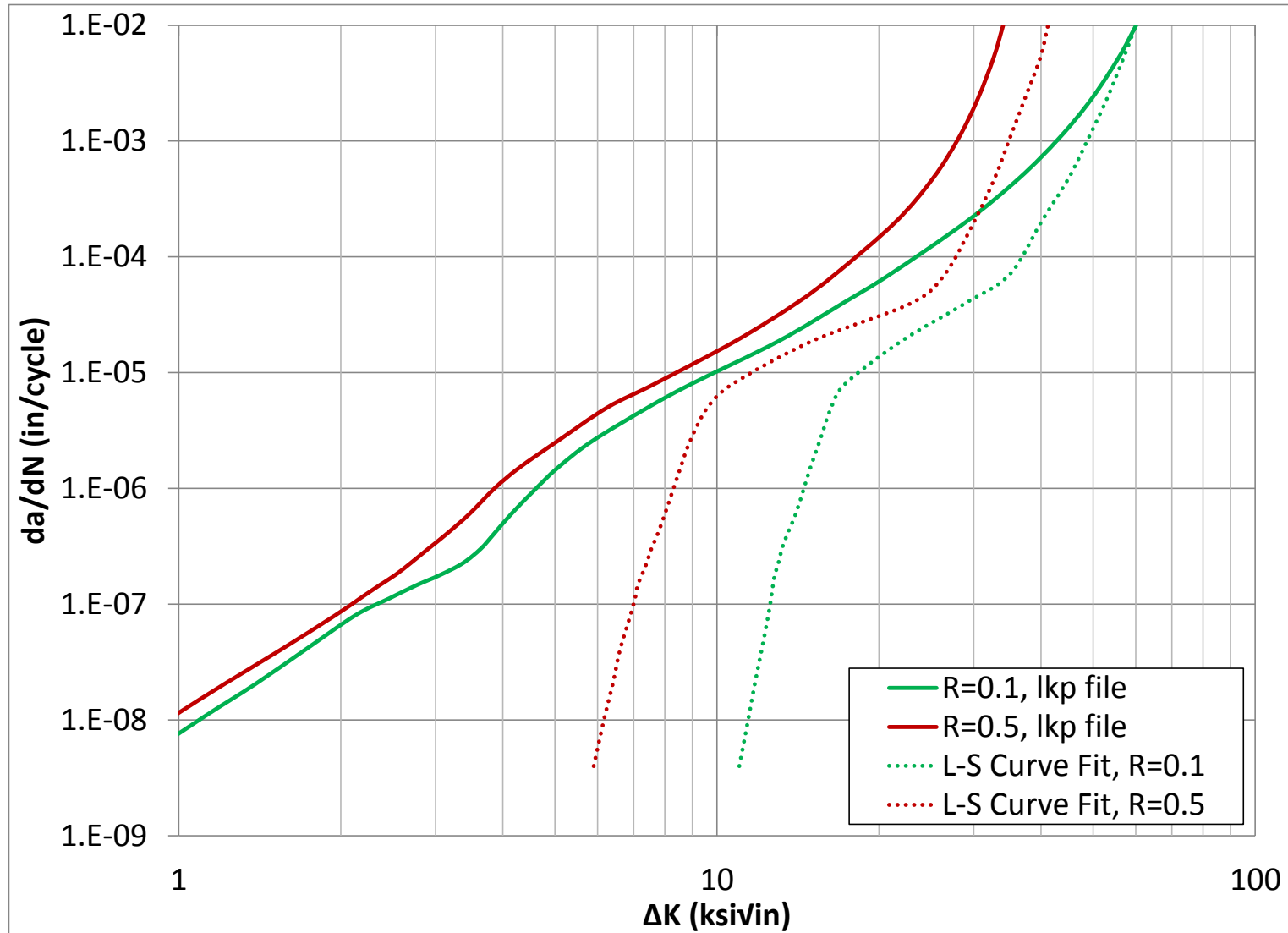


Curve Fit of Test Data: 7175-T74 | L-S





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



Version 5.03 Alfa

Version 5.02.02.16

Windows 8 / 7 / VISTA / XP SP3

Destroy after

1/1/2016

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New AFGROW Version: Lookup File Interface

The screenshot shows a software window titled "Materials" with a close button in the top right corner. On the left side, there is a tree view with the following structure:

- Material List
 - General
 - Data Set**
 - C Direction
 - A Direction

The main area of the window contains two text input fields:

- "Material name:" with the text "Material" entered.
- "Description:" with the text "Material Description" entered.

At the bottom of the main area, there is a checked checkbox labeled "Material properties crack direction dependent".

At the bottom of the window, there is a row of buttons: OK, Cancel, Apply, Add, Delete, Read, Save, and Help.



New AFGROW Version: Lookup File Interface

Materials

Material List

- General
- Data Set
 - C Direction
 - A Direction

Input values of Delta_K for da/dN values and up to 10 different R(stress ratio) values. Matrix must have at least two R values and two da/dN values. Input Delta_K for R >= 0, input Kmax for R < 0.0

Name: Material

Number of da/dN Sets: 27 Number of R Sets: 2

		R[1]	R[2]
		0.1	0.601
da/dN[1]	1.00e-009	2.606	1.38
da/dN[2]	3.00e-009	2.636	1.409
da/dN[3]	1.00e-008	2.673	1.503
da/dN[4]	2.00e-008	2.685	1.66
da/dN[5]	4.00e-008	2.729	1.897
da/dN[6]	6.00e-008	2.792	2.089
da/dN[7]	1.00e-007	2.954	2.355
da/dN[8]	2.00e-007	3.307	2.814
da/dN[9]	3.00e-007	3.605	3.133
da/dN[10]	4.00e-007	3.839	3.383
da/dN[11]	6.00e-007	4.209	3.744
da/dN[12]	1.00e-006	4.781	4.355
da/dN[13]	2.00e-006	5.696	5.218
da/dN[14]	4.00e-006	6.873	6.254
da/dN[15]	1.00e-005	8.825	8.014
da/dN[16]	2.00e-005	10.684	9.61

Ultimate Strength: 66

Young's Modulus: 10500

Coefficient of Thermal Expansion: 1.25e-005

Poisson's Ratio: 0.33

Upper limit on da/dN, DADNHI: 0.01

Lower limit on da/dN, DADNLO: 1e-009

Plane Stress Fracture Toughness, KC: 62.777

Plane Strain Fracture Toughness, KIC: 35

Delta K threshold value @R=0: 2.831

Yield Strength, YLD: 47

Lower limit on R shift (Max: 0): -0.3

Upper limit on R shift (0, 1): 0.63

OK Cancel Apply Add Delete Read Save Help



New AFGROW Version: Lookup File Interface

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da/dN[9]	3.00e-007	3.605	3.133
da/dN[10]	4.00e-007	3.839	3.383
da/dN[11]	6.00e-007	4.209	3.744
da/dN[12]	1.00e-006	4.781	4.355
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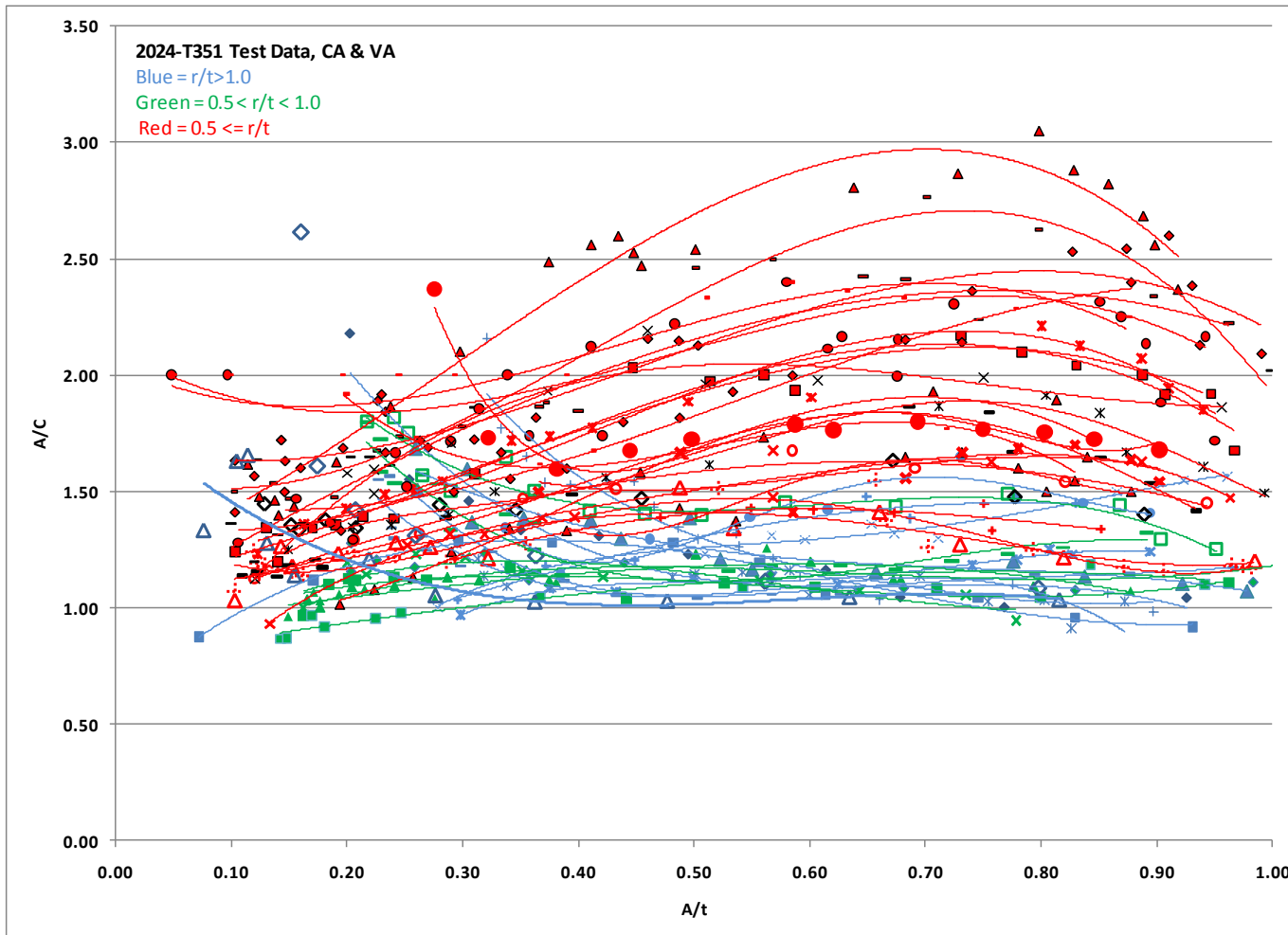
OK Cancel Apply Add Delete Read Save Help

Equilibrium Crack Aspect Ratio, Cont.



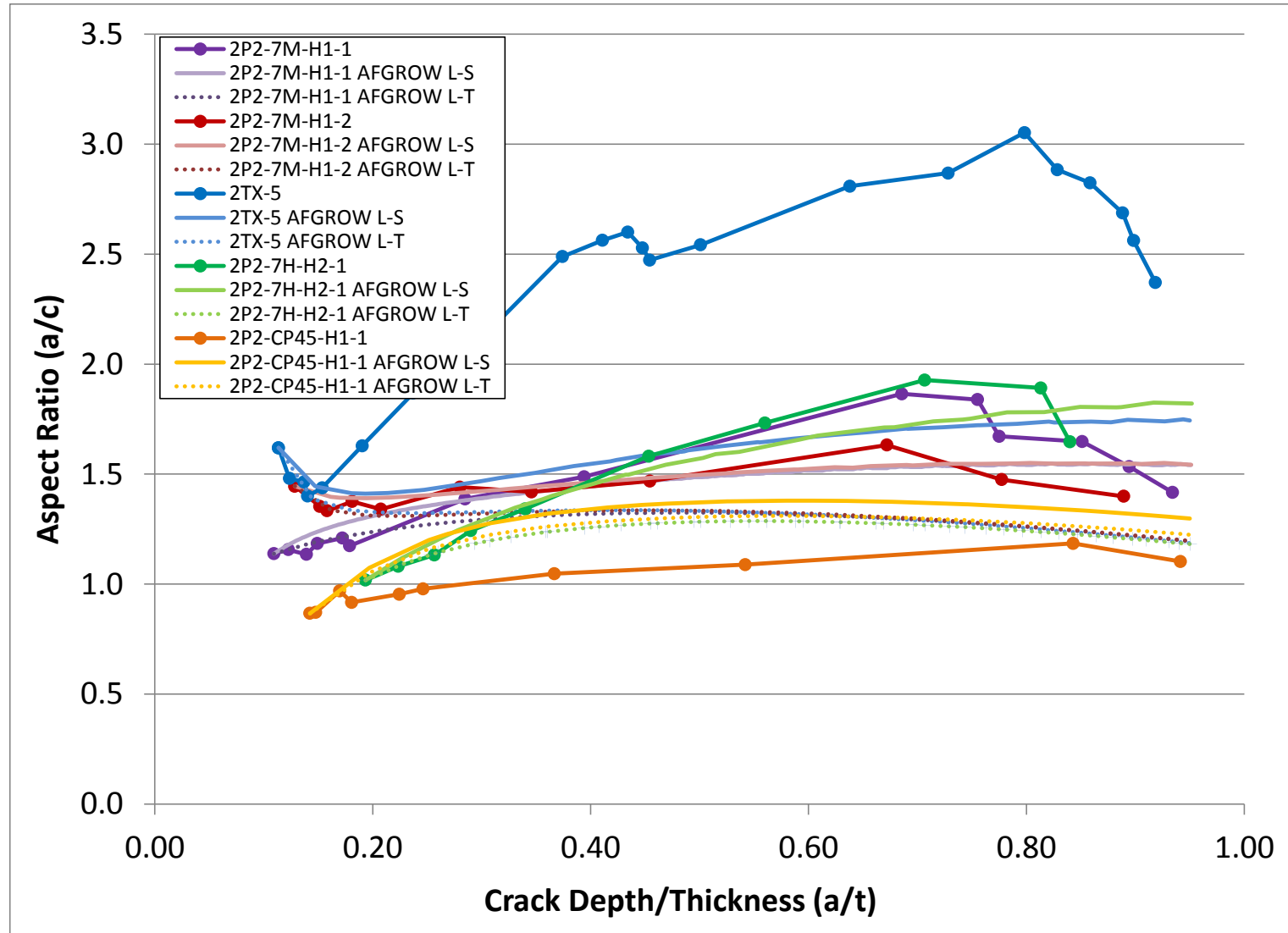
(Pilarczyk, 2011)

2024-T351 Data



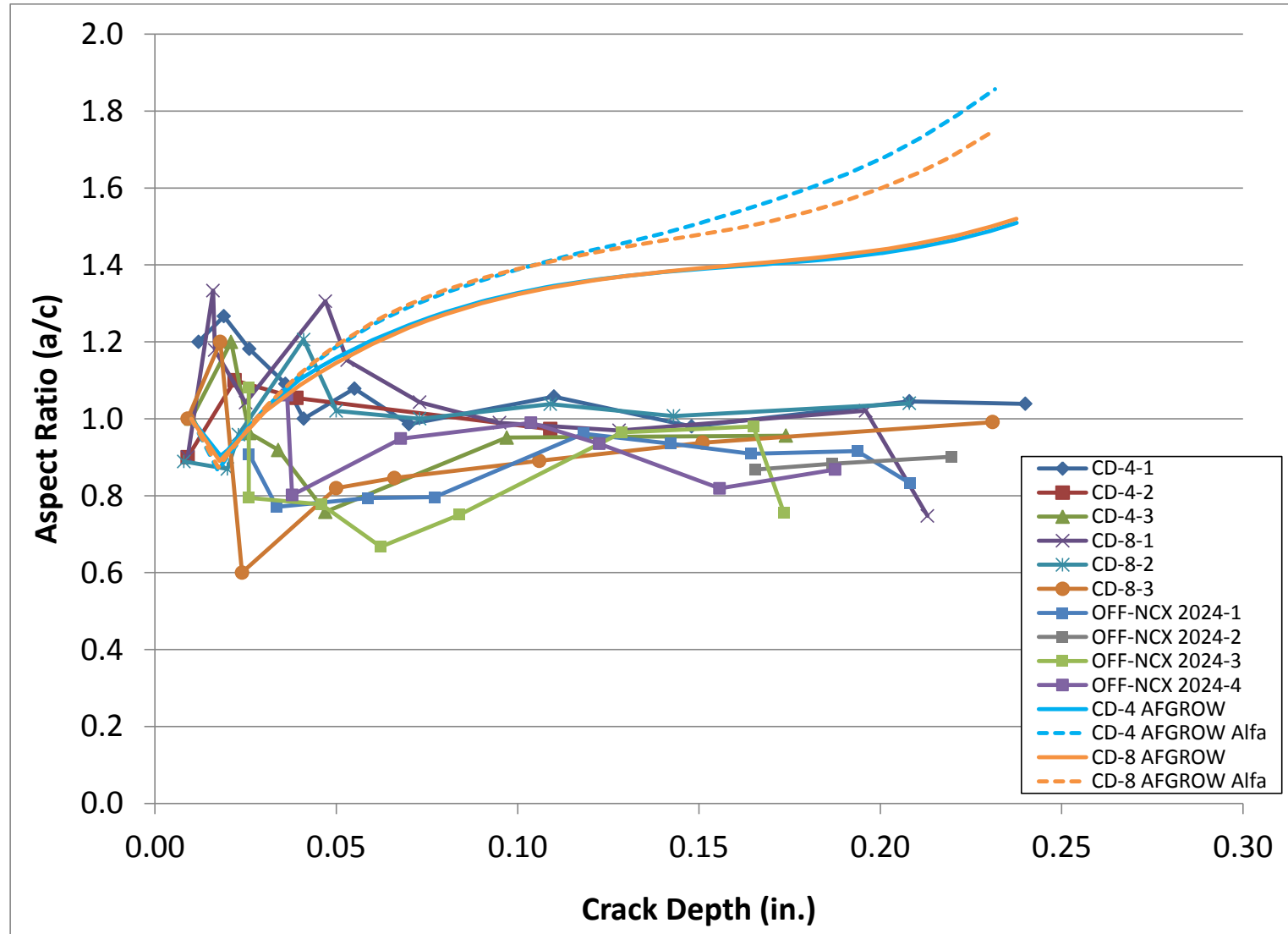


Aspect Ratio Comparisons: 2024-T351, VA





Aspect Ratio Comparisons: 2024-T351, CA

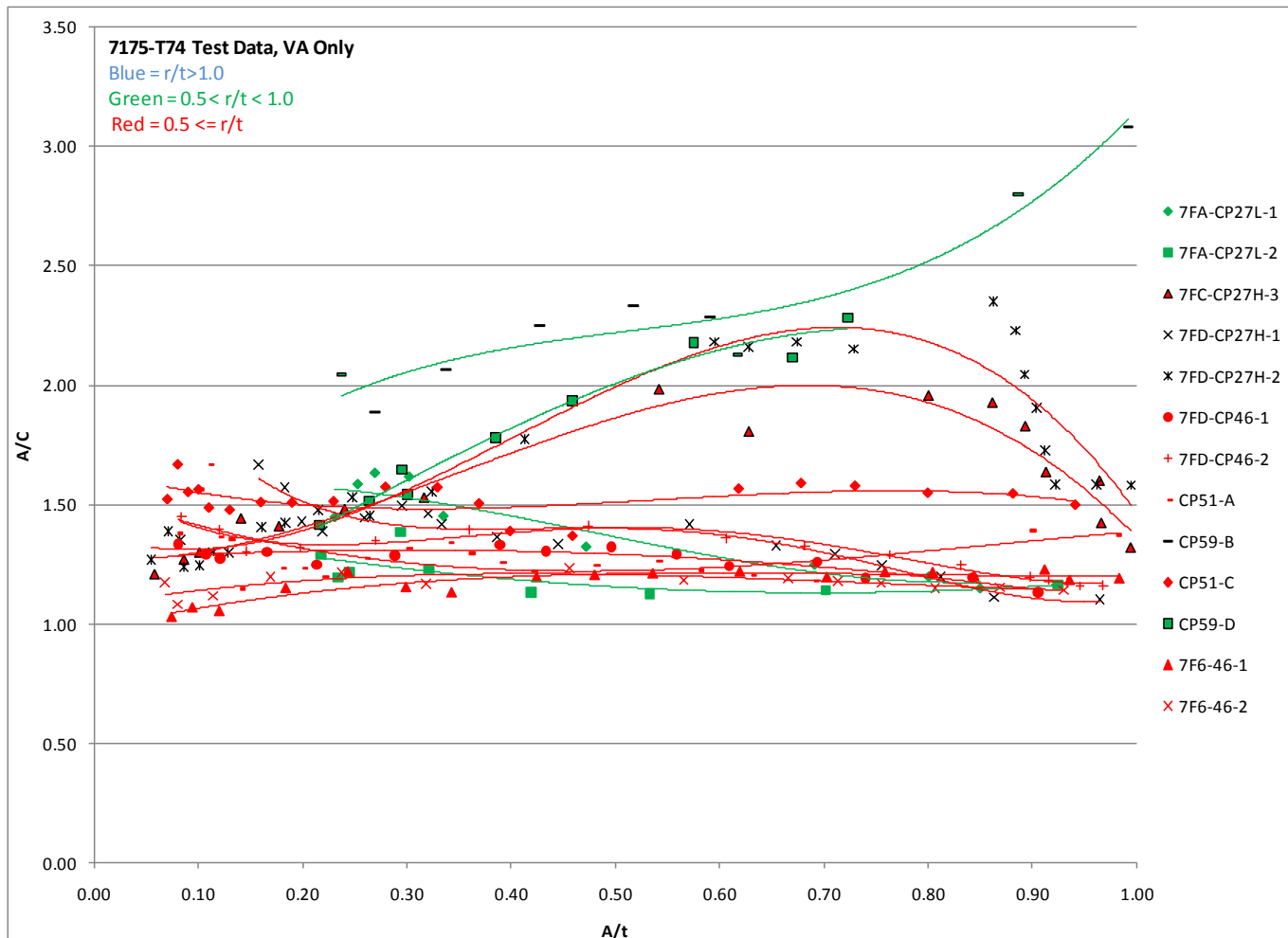


Equilibrium Crack Aspect Ratio, Cont.



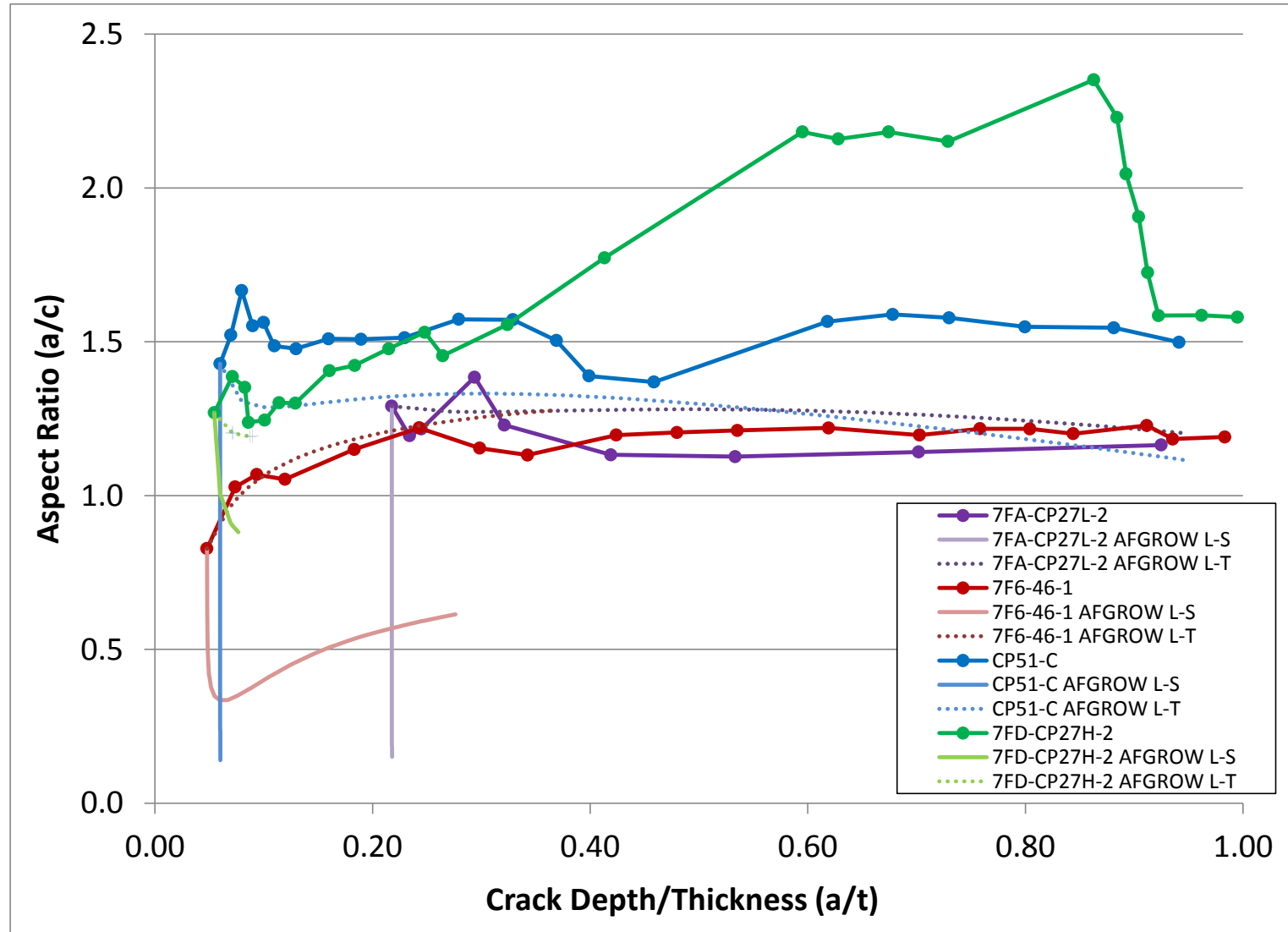
(Pilarczyk, 2011)

7175-T74 Data



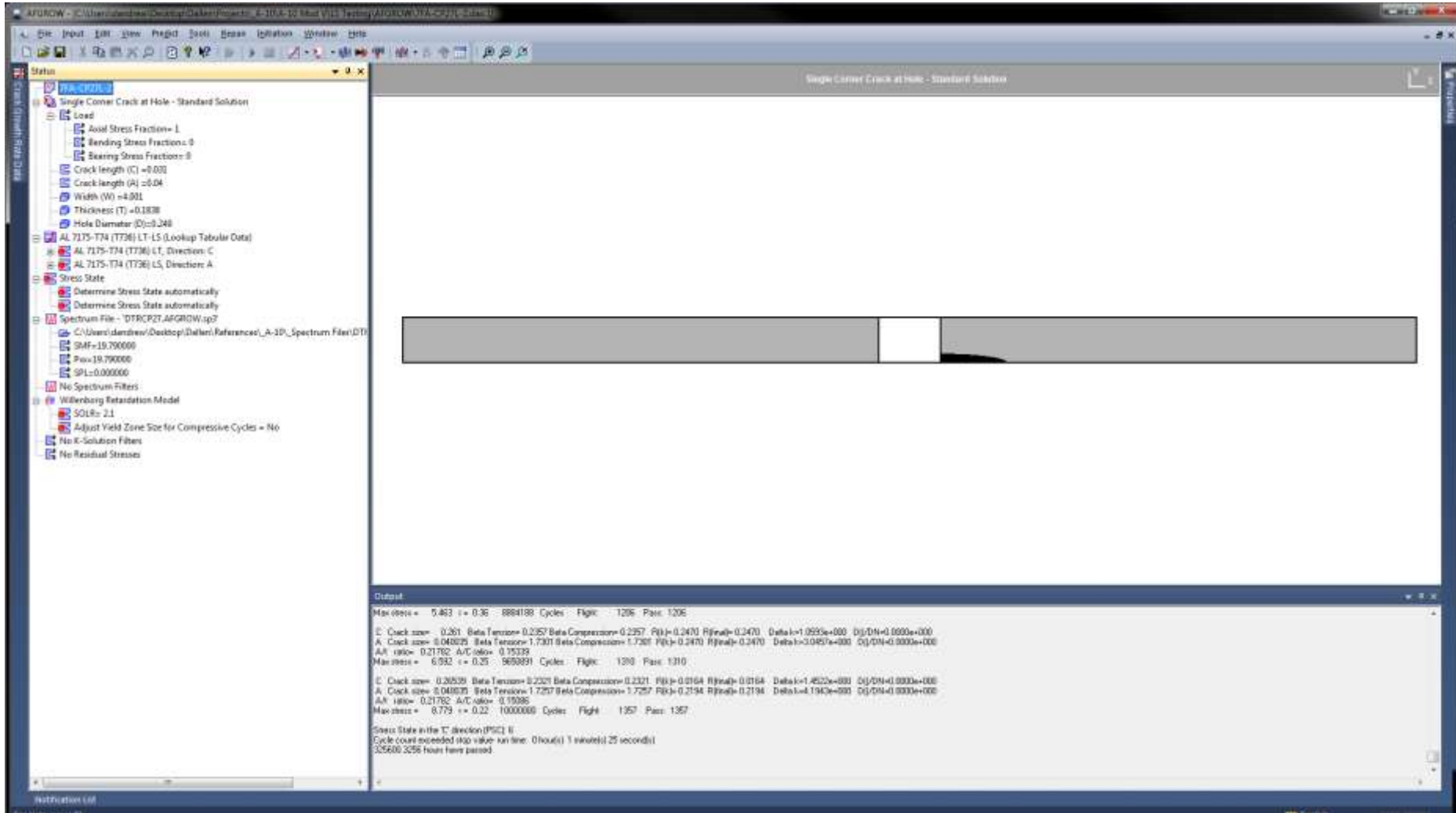


Aspect Ratio Comparisons: 7175-T74, VA





Aspect Ratio Comparisons: 7175-T74



■ 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**

- 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?

