# Development of Fatigue Crack Growth Rates from Corner Crack Tests

SOUTHWEST RESEARCH INSTITUTE®

Luciano Smith, James Feiger, and Mark Thomsen

AFGROW User Workshop
September 2017

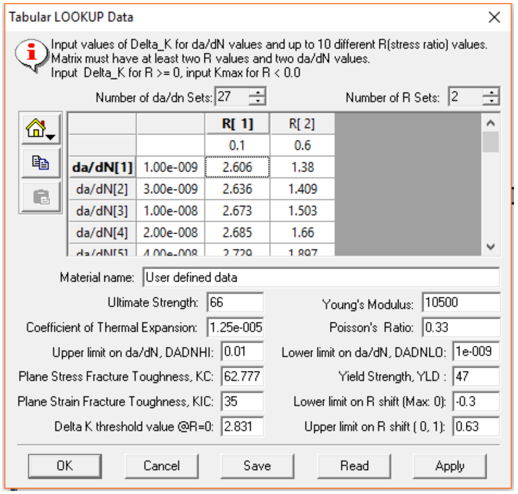
Distribution A: Approved for public release; unlimited distribution.
Reference Number: 2017-08-30_WWA-004, Case #75ABW-2017-0044

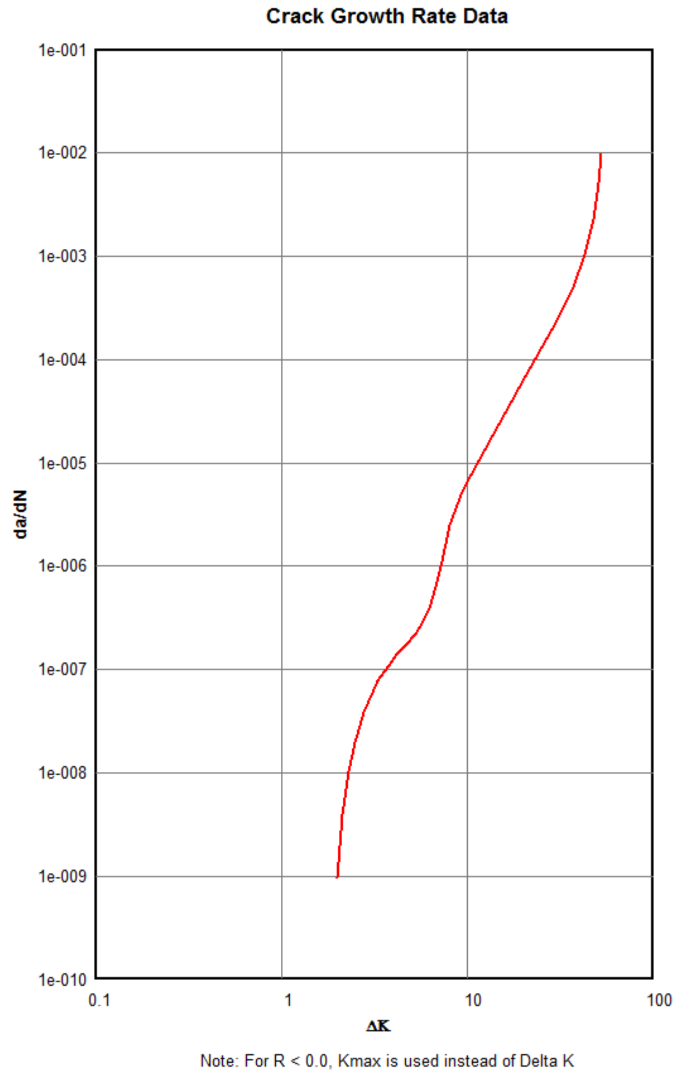
# Introduction

- Fatigue crack growth rates
  - As incorporated into AFGROW
  - As tested
  - ASTM E647
    - Current requirements
    - Upcoming changes
- Corner crack growth rate testing
  - Motivation
  - Description
  - Results

# Growth rates in AFGROW

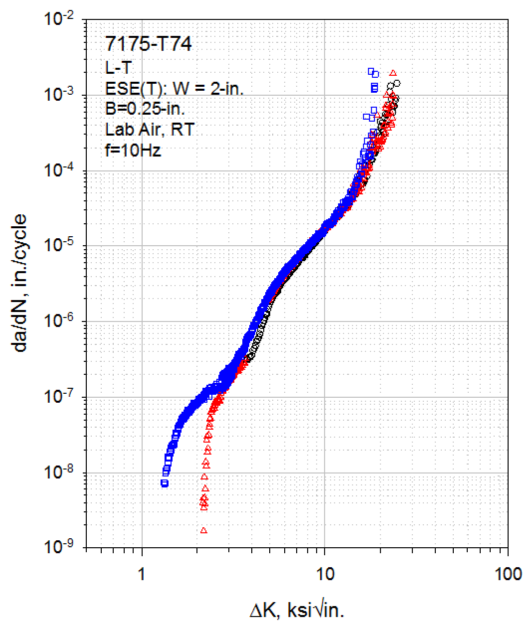
- Five options
  - Forman equation
  - Harter-T method
  - NASGRO (v3.0) equation
  - Tabular lookup
  - Walker equation
- Can develop smooth fit to data
- Tabular input gives most flexibility and accuracy with non-sigmoidal data

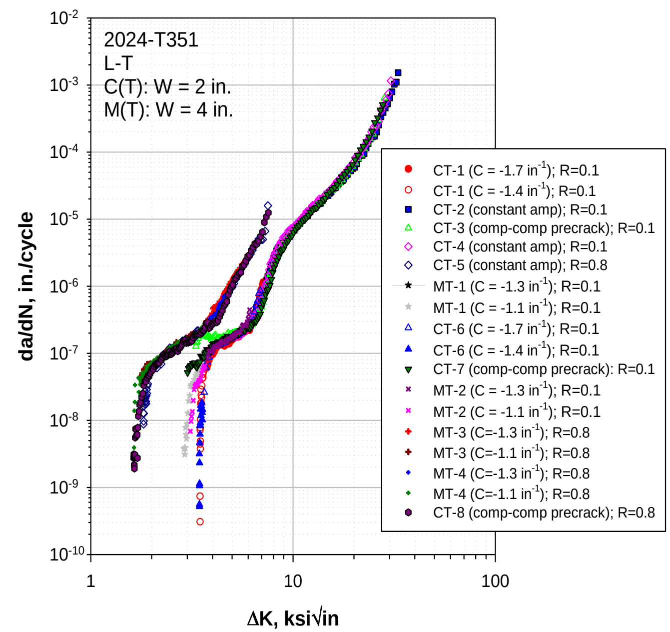


# Growth rates as tested

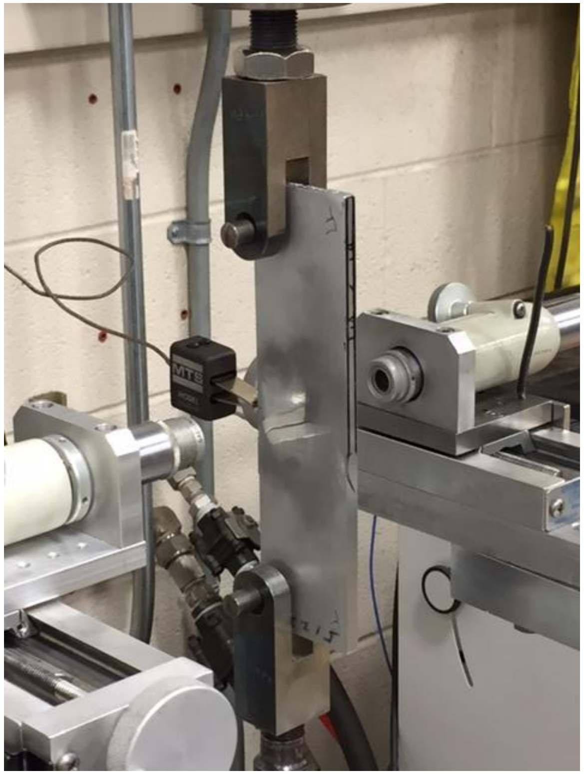
- Test data can often be less smooth and therefore difficult to fit
- Variability when testing multiple specimens
  - Sometimes caused by residual stresses, crack branching, etc.
  - At lower growth rates and stress ratios, often crack closure
    - Plasticity induced – load history
    - Roughness induced – crack geometry and material microstructure



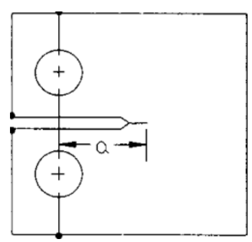
# ASTM E647

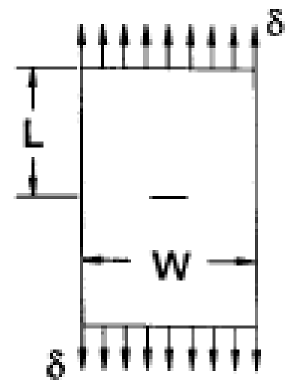
- Standard Test Method for Measurement of Fatigue Crack Growth Rates
  - Specimen configuration
  - Test procedure
  - Calculation of growth rates
  - Reporting requirements

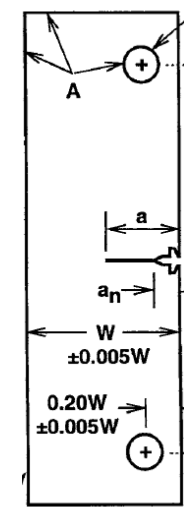


# ASTM E647

- Standard Test Method for Measurement of Fatigue Crack Growth Rates
  - Specimen configuration
    - Any specimen type is allowed if the K solution is known
      - "Specimen configurations other than those contained in this method may be used provided that well-established stress-intensity factor calibrations are available"
    - Three specimens are defined:
      - Eccentrically-loaded single edge crack tension: ESE(T)
      - Middle tension: M(T)
      - Compact: C(T)



# ASTM E647

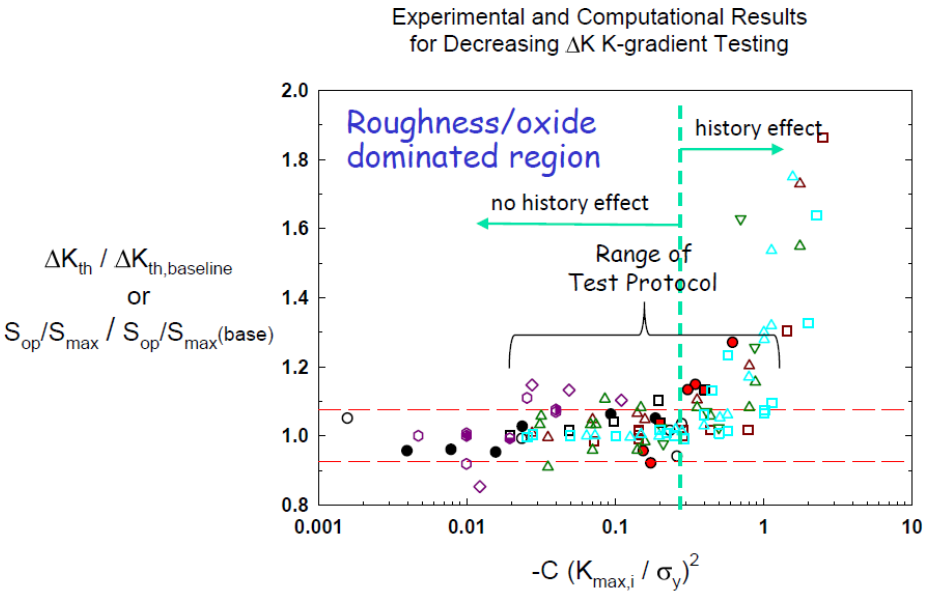
- Standard Test Method for Measurement of Fatigue Crack Growth Rates
  - Specimen configuration
  - Test procedure
    - Number of tests
    - Precracking method
    - Application of load
      - Constant force-amplitude or K-control for rates above $10^{-8}$ m/cycle
      - K-decreasing for rates below $10^{-8}$ m/cycle (near-threshold)
        - » Rate of load shedding is limited to prevent load history effects on growth rates (crack growth retardation)

$$C = \left(\frac{1}{K}\right) \cdot \left(\frac{\mathrm{d}K}{\mathrm{d}a}\right) > -0.08\ \mathrm{mm}^{-1}\ (-2\ \mathrm{in.}^{-1})$$

# ASTM E647

- Upcoming changes to near-threshold procedures
  - K-decreasing procedure being moved to an appendix
    - Consistency with compression precracking procedure, which is currently in an appendix
  - Load shedding gradient changing from C to a new unitless parameter:

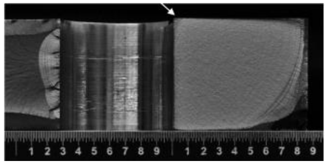
$$-C\left(\frac{K_{max,i}}{\sigma_{YS}}\right)^2 < 0.1$$



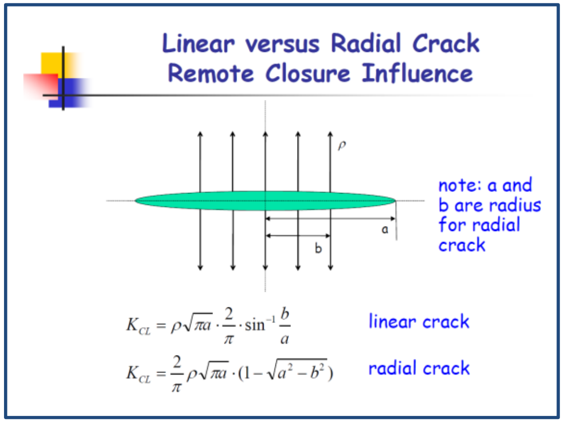

(Ref: ASTM E08.06.06 meeting minutes, November 15, 2016

# Motivation for corner crack testing

- Ability to gather L-T and L-S growth rate data in one test
- The standard specimens used for crack growth rate testing are all one-dimensional through cracks
  - The majority of analysis life is as corner crack



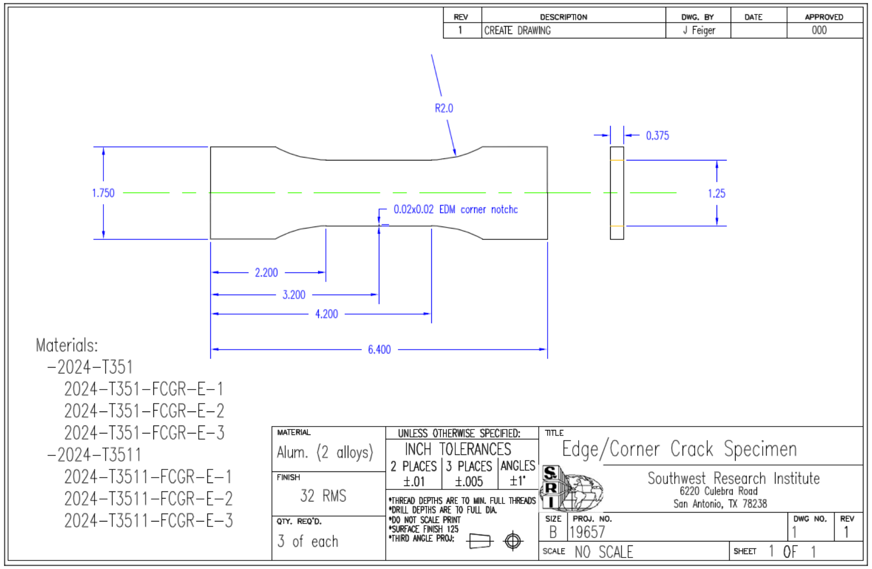
- When loading history is properly accounted for (minimizing plasticity induced crack closure), roughness induced closure dominates at low $\Delta K$
  - Closure effect is smaller for radial crack versus linear crack (bulk material constraint)

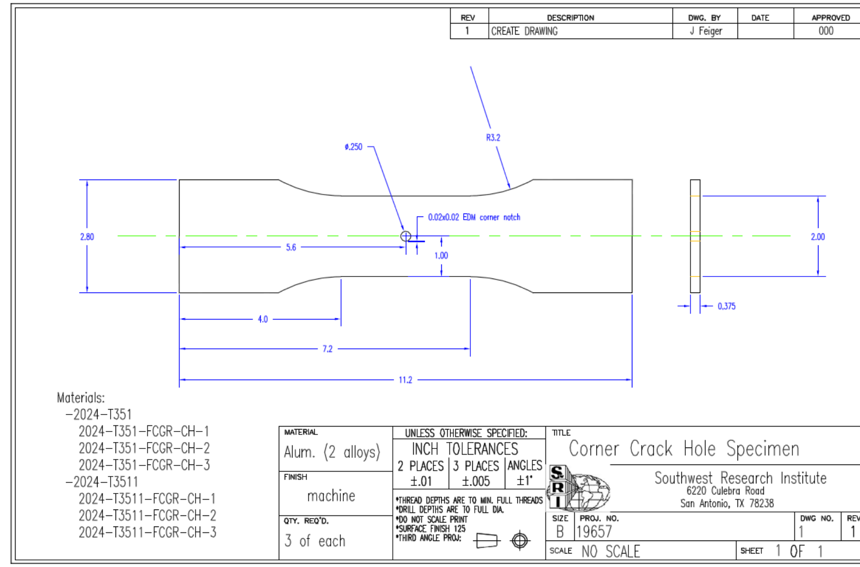



(Ref: ASTM E08.06.06 meeting minutes, November 15, 2016

# Description of corner crack testing

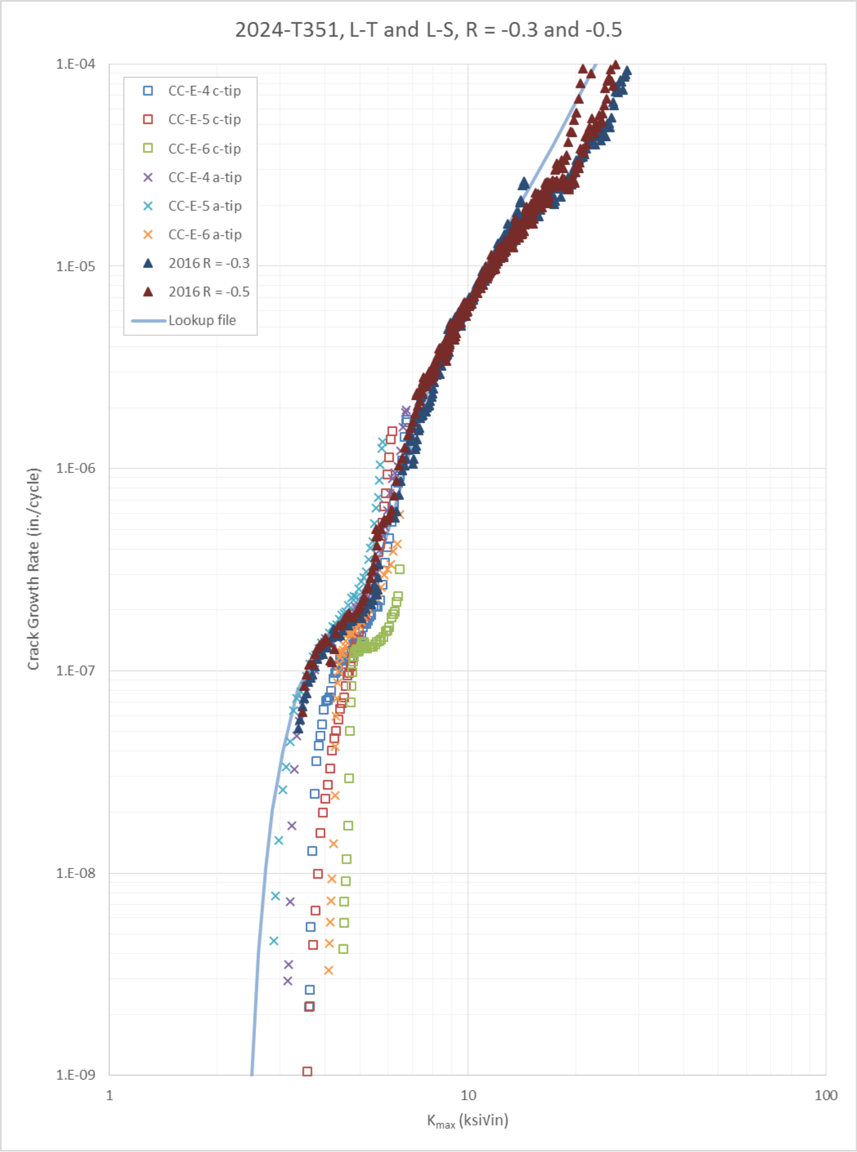
- All procedures follow E647, with two non-standard specimens



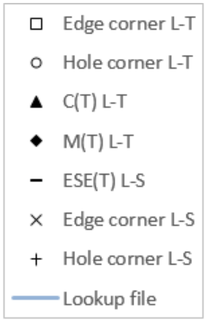




- R = 0.1 and -0.3
- Load shedding controlled by DCPD
  - C = -4 $in^{-1}$ $(0.035 < -C\,(K_{max,i} / \sigma_y)^2 < 0.097)$
  - Pre-test assumption of aspect ratios for a-tip K input
  - Post-test correction of applied K for da/dN-ΔK curves

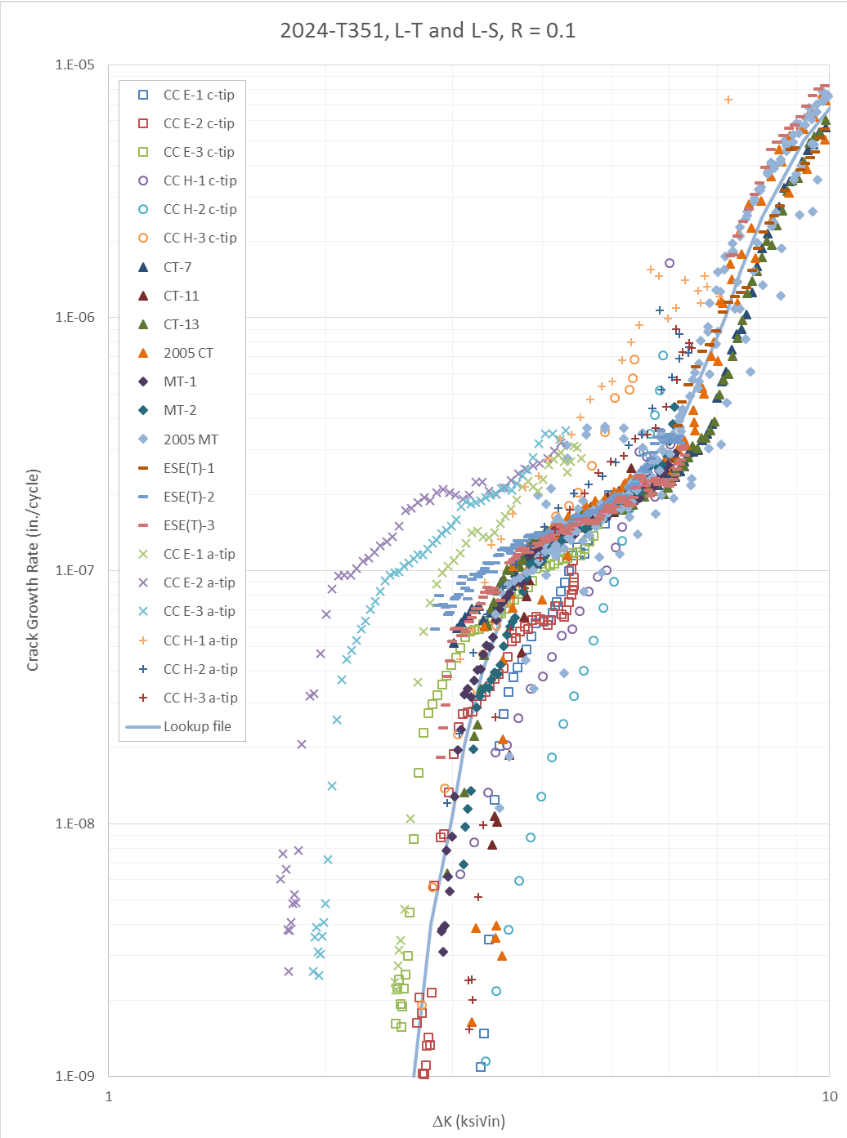
# Test results: T351 L-T and L-S, R = -0.3



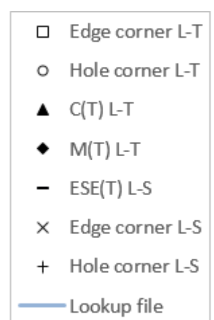

- Mostly consistent with M(T) data
- L-S (a-tip) data shows lower threshold than L-T (c-tip)
  - Very slightly lower than M(T)



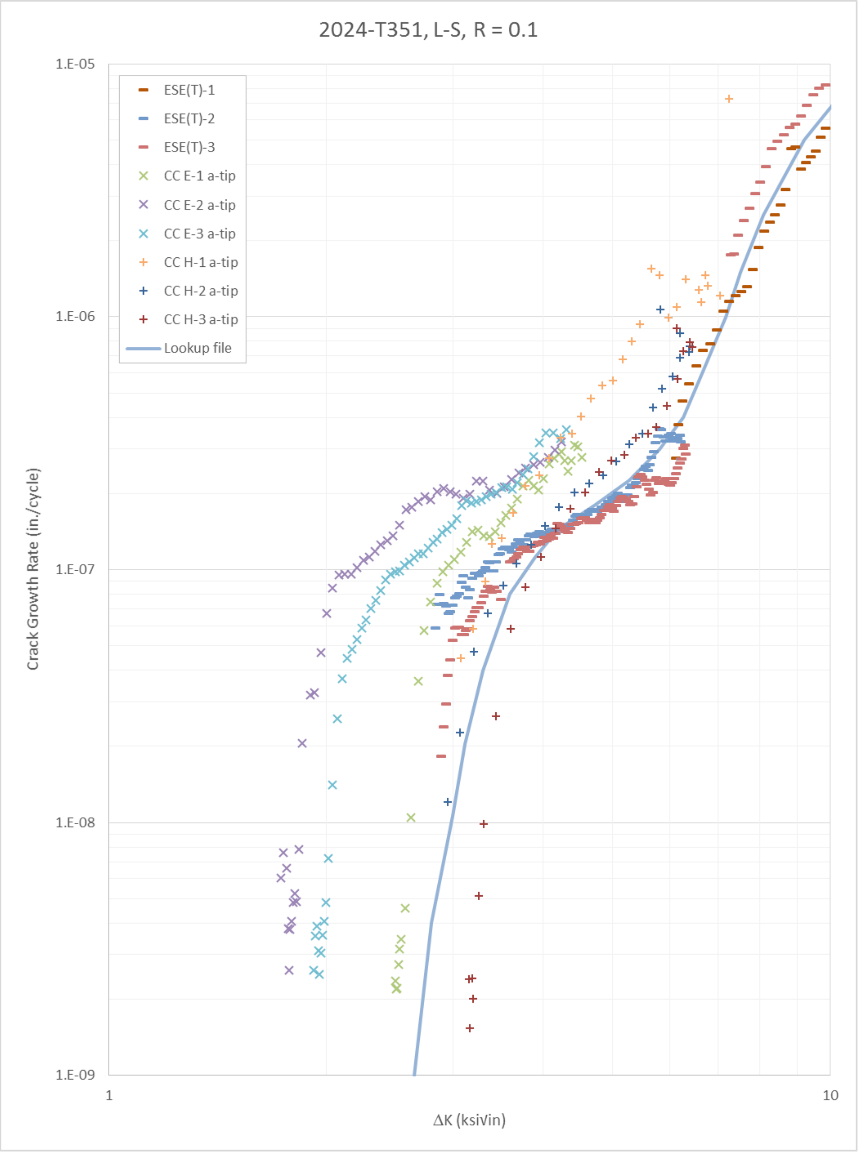
# Test results: T351 L-T and L-S, R = 0.1



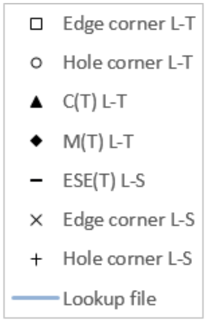

- L-S (a-tip and ESE(T)) data shows lower threshold than L-T (c-tip, C(T), and M(T)) data
- L-S data shows faster rates than the AFGROW lookup file
  - Potential for improved accuracy in corner crack aspect ratios



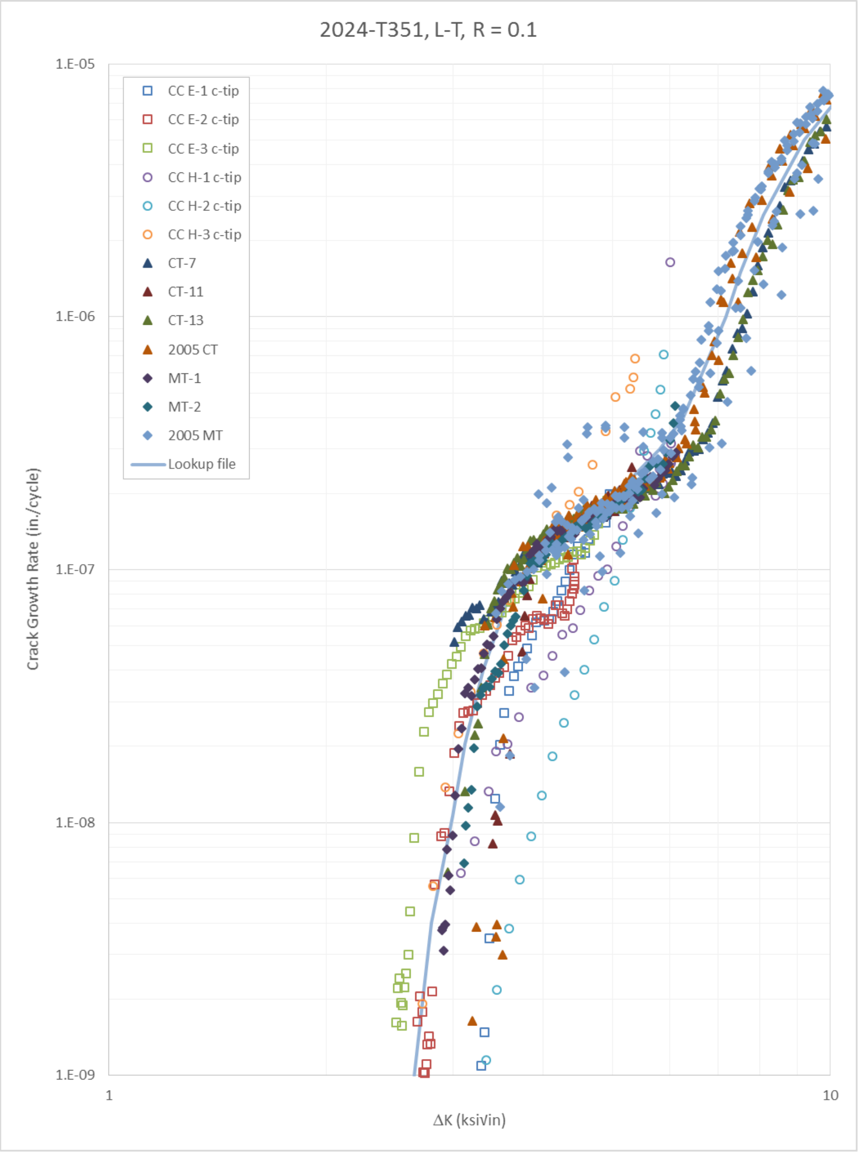
# Test results: T351 L-S, R = 0.1



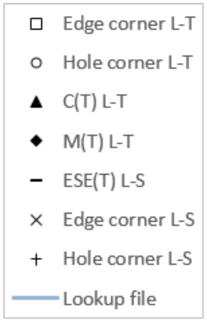

- Edge corner crack data shows lower threshold than both ESE(T) and hole corner crack



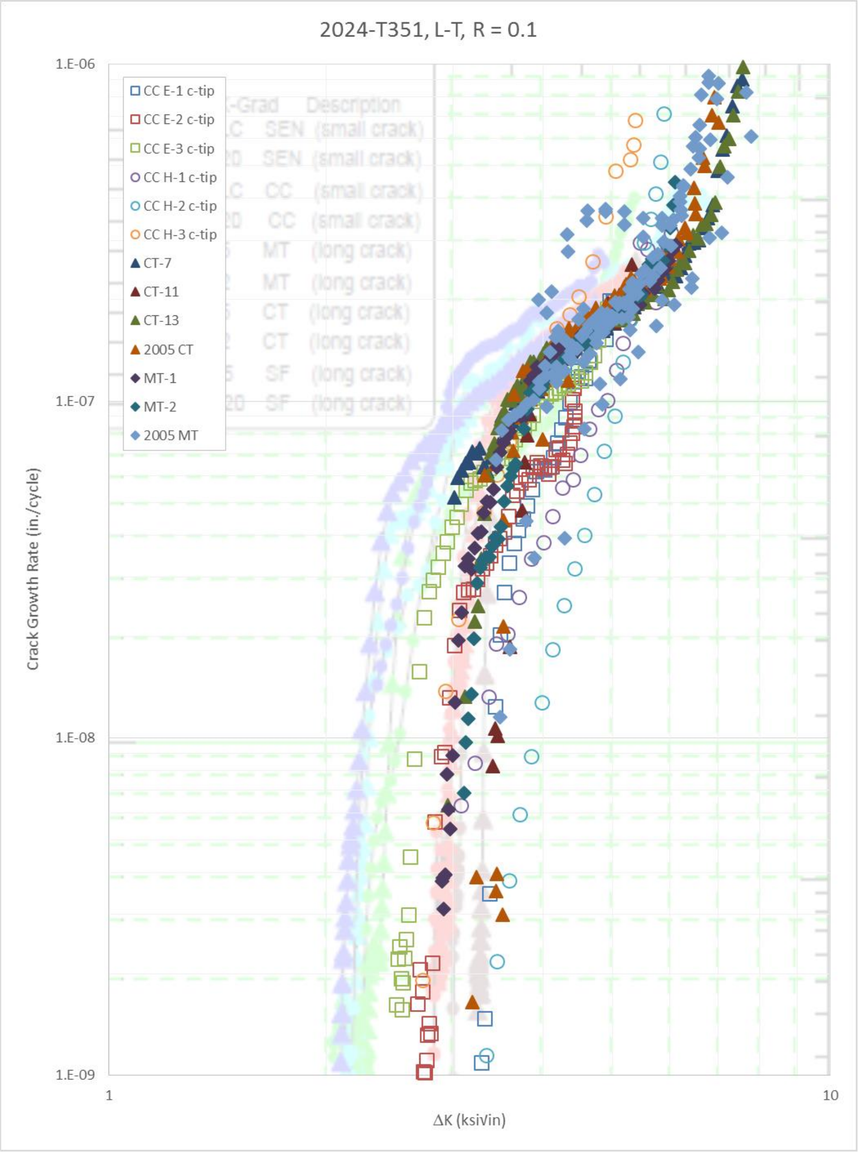
# Test results: T351 L-T, R = 0.1




- Corner crack data consistent with C(T) and M(T) data
- Edge corner crack data shows lower threshold than hole corner crack

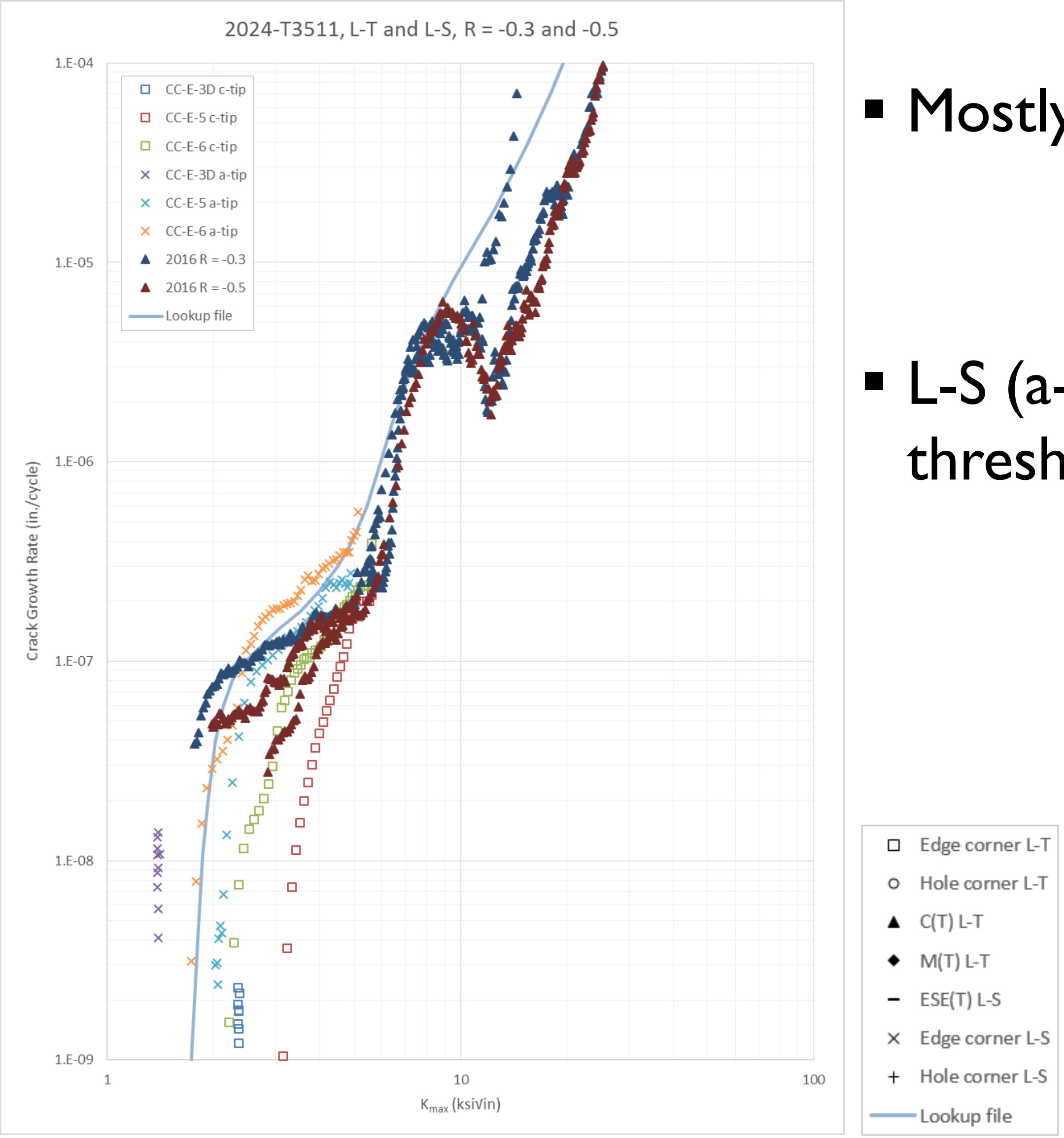


# Test results: T351 L-T, R = 0.1



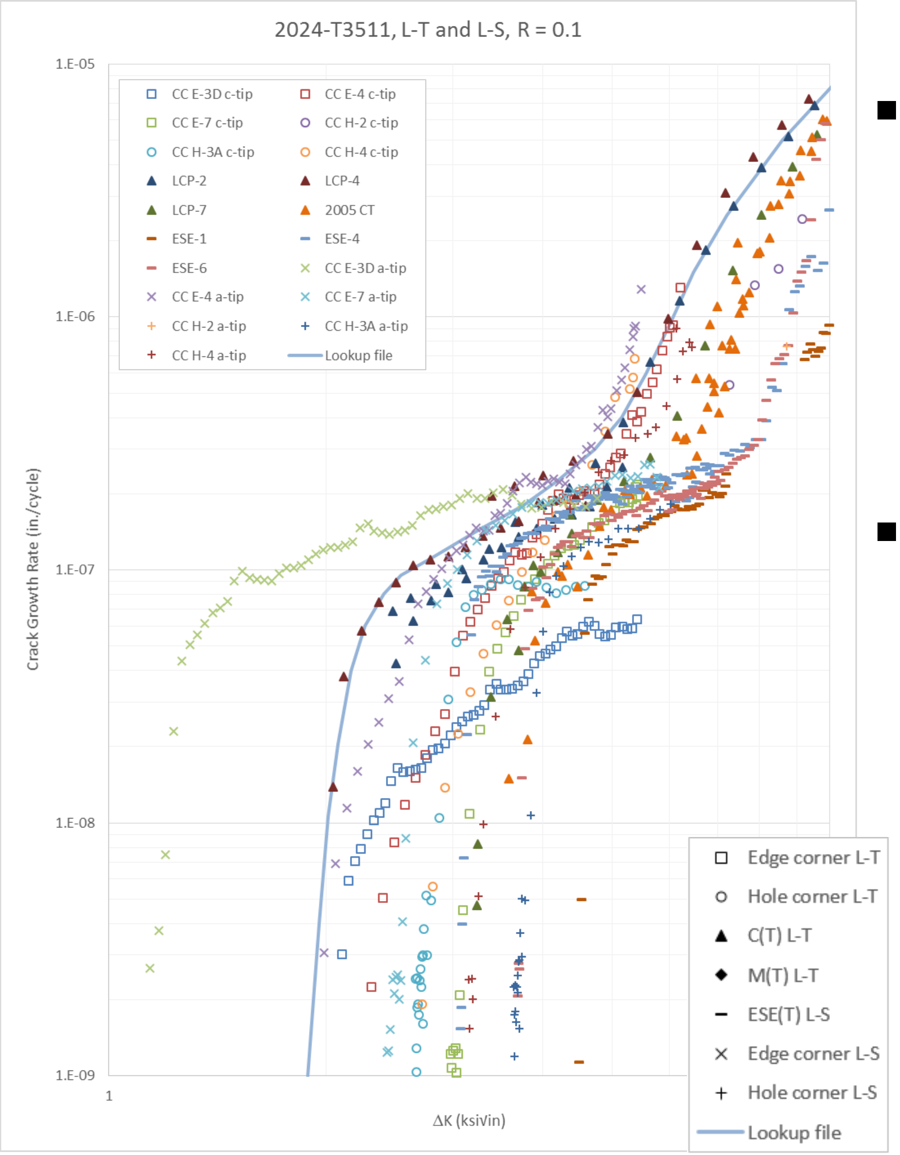

- Comparison against Keith Donald data presented at ASTM E08.06, November 2016
  - Through crack results match very well
  - Corner crack results:
    - SwRI consistent with through crack results
    - Donald shows smaller threshold
- Inconsistency caused by C?
  - SwRI: -4 $in^{-1}$
  - Donald: -20 $in^{-1}$
    - $\Delta a$ range ~ 0.04”

# Test results: T3511 L-T and L-S, R = -0.3



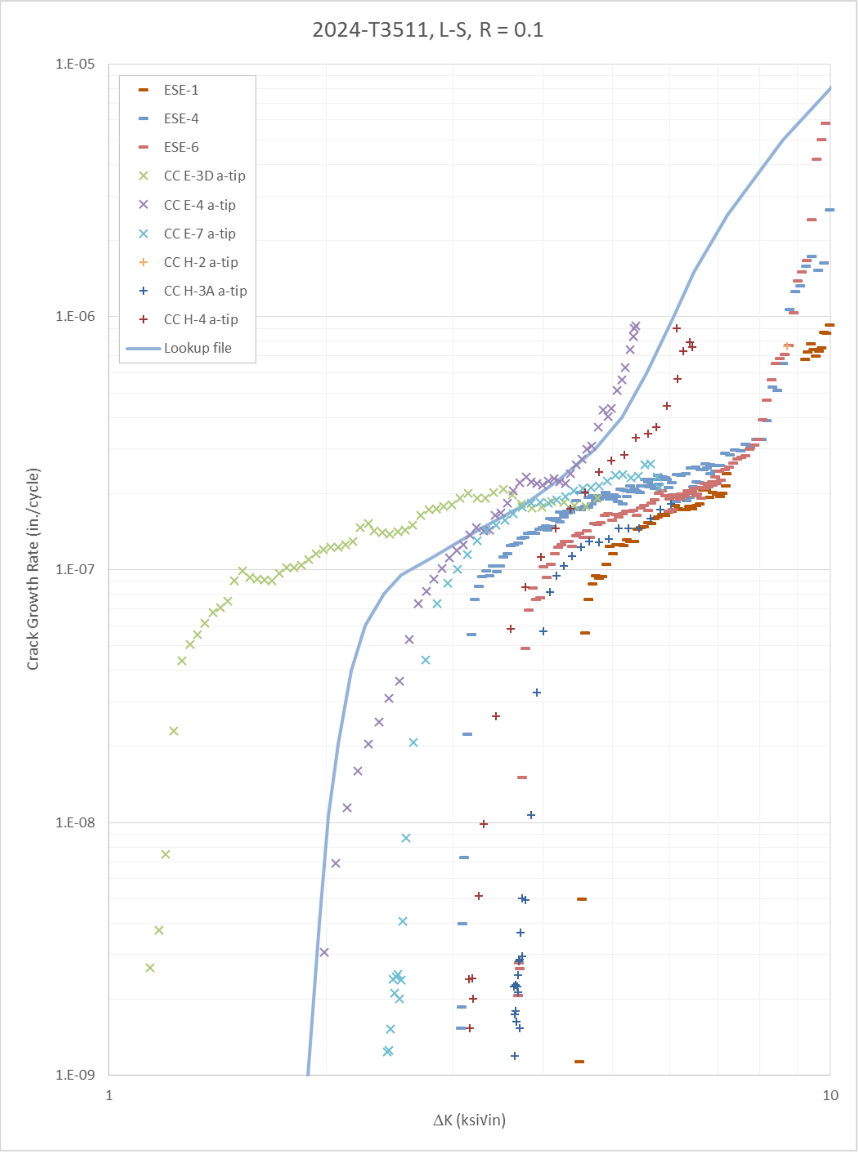

- Mostly consistent with M(T) data
- L-S (a-tip) data shows lower threshold than L-T (c-tip)

# Test results: T3511 L-T and L-S, R = 0.1

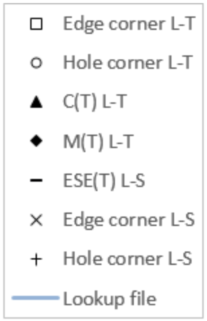



- L-S (a-tip and ESE(T)) and L-T (c-tip, C(T), and M(T)) data show similar threshold values
  - Not including one outlier
- Corner crack and through crack data show lower rates than the AFGROW lookup file
  - Lookup file is conservative, but not unrealistic
  - Not including one outlier

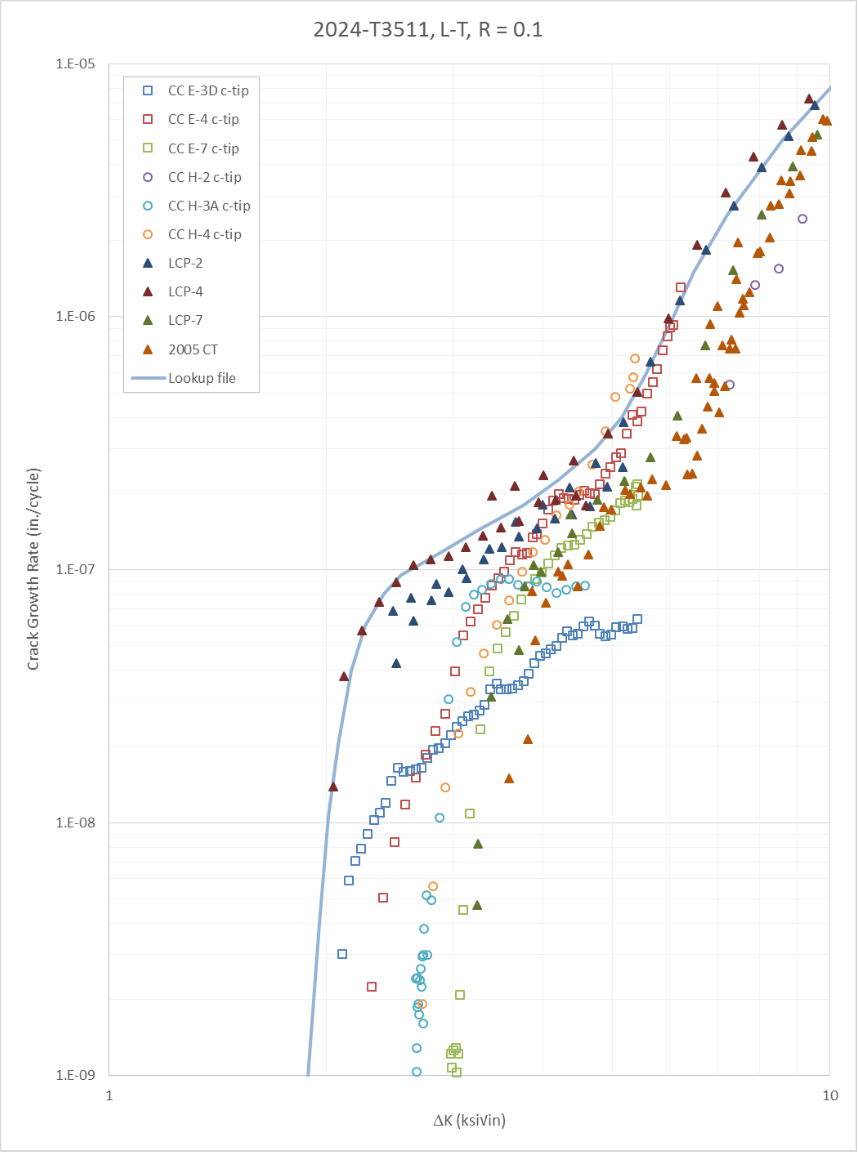
# Test results: T3511 L-S, R = 0.1



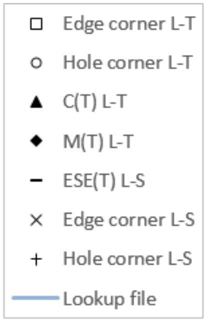

- Edge corner crack data shows lower threshold than both ESE(T) and hole corner crack



# Test results: T3511 L-T, R = 0.1




- Corner crack data consistent with C(T) and M(T) data
- Edge and hole corner crack rates are similar



# Conclusions

- Successfully developed da/dN-ΔK curves from E647 testing using corner crack specimens
- Data developed for both L-T and L-S cracking
  - Simpler method for L-S data than using through crack specimens
  - Thin specimens possible
- Method did not decrease variability seen in near-threshold data
  - Cracked edge specimens more consistent and more in line with expectations than cracked hole specimens