Crack growth rate testing in the surface (L-T), through-thickness (L-S), and diagonal (L-TS) directions

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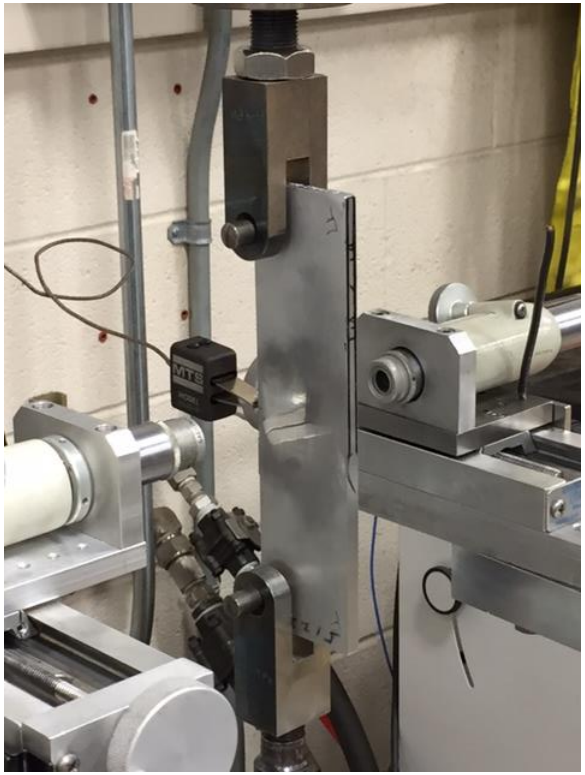
Introduction

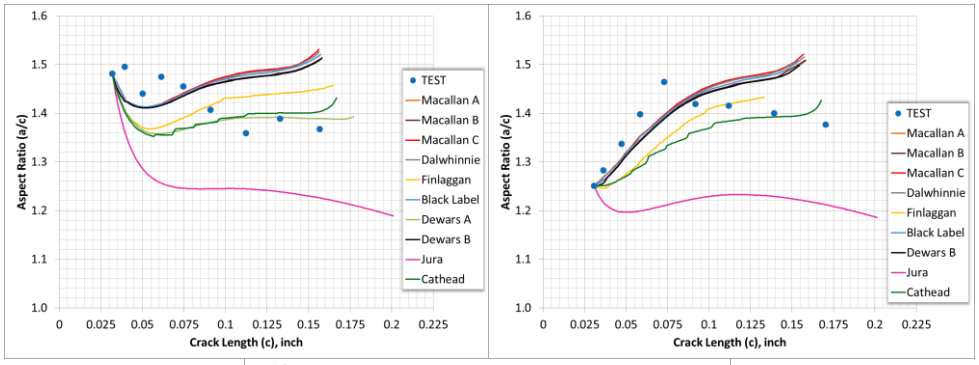
- Thanks to Mark Thomsen, Jacob Warner, and Kaylon Anderson from A-10 ASIP

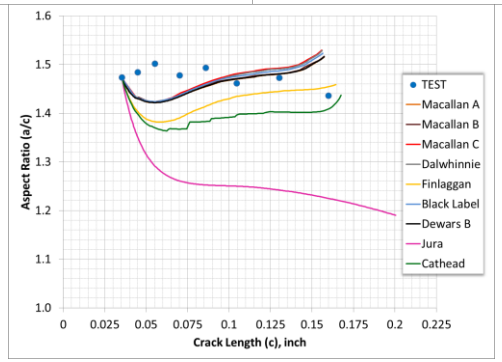
- Testing for L-T and L-S growth
  - Motivation
  - Procedure
  - Results
- Testing for L-TS direction
  - Motivation
  - Procedure
  - Results
- Impact on analysis

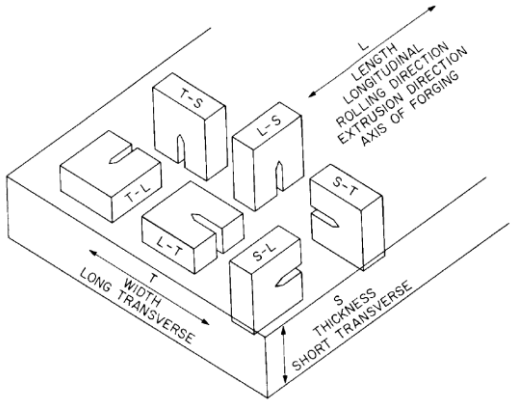


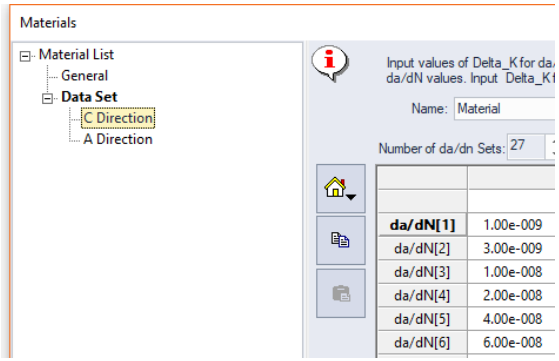
Motivation for corner crack testing

- The majority of analysis life is as corner crack
- Analytical corner crack aspect ratios do not always match actual crack growth well
  - Growth rates potentially different in L-T and L-S directions?



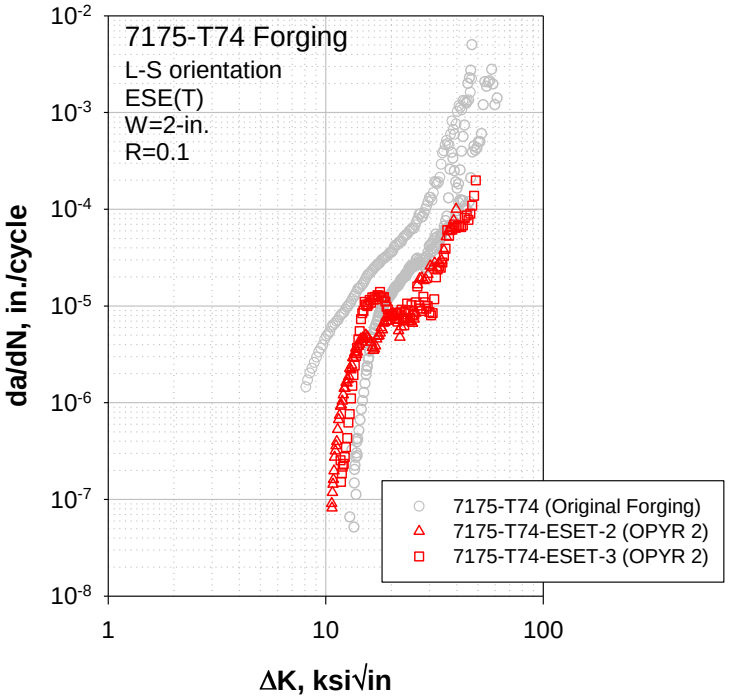


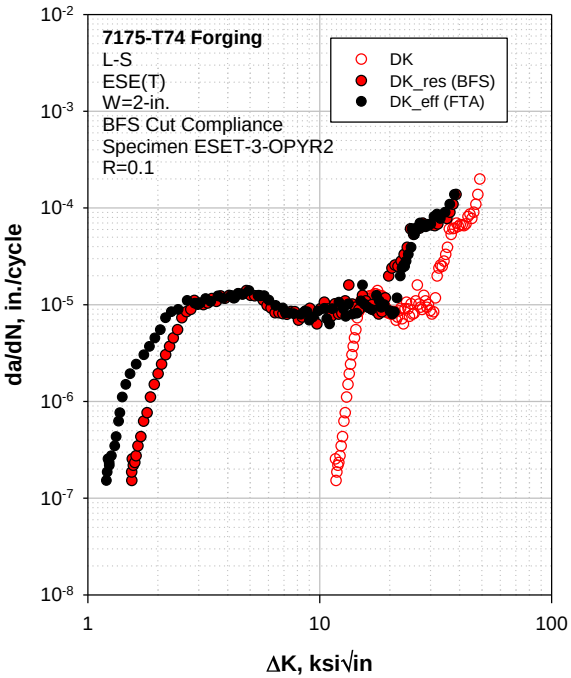




Motivation for corner crack testing

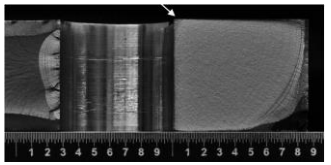
- Initial L-S testing performed using standard ASTM E647 ESE(T) (through crack) specimens
  - Some struggles because of initial thickness required



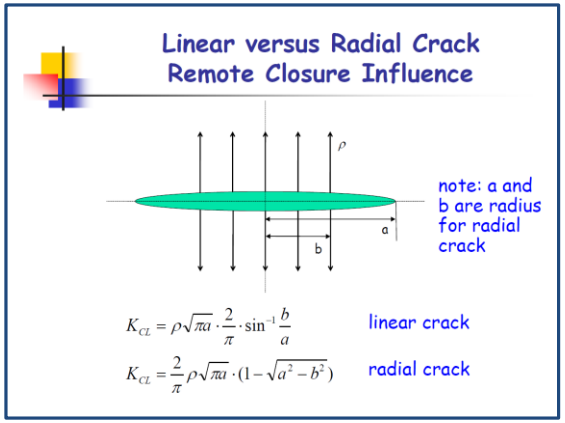


Benefits of corner crack testing

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



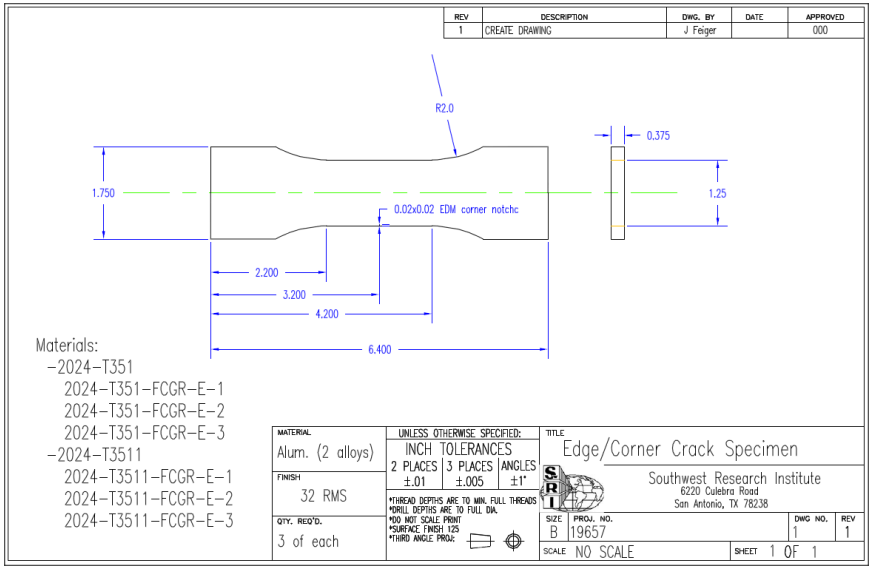
- Specimens can be cut from thin material (no residual stresses)
- When loading history is properly accounted for (minimizing plasticity induced crack closure), roughness induced closure dominates at low ΔK
  - Closure effect is smaller for radial crack versus linear crack (bulk material constraint)



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

Corner crack test procedure

- All procedures follow E647 with non-standard specimens



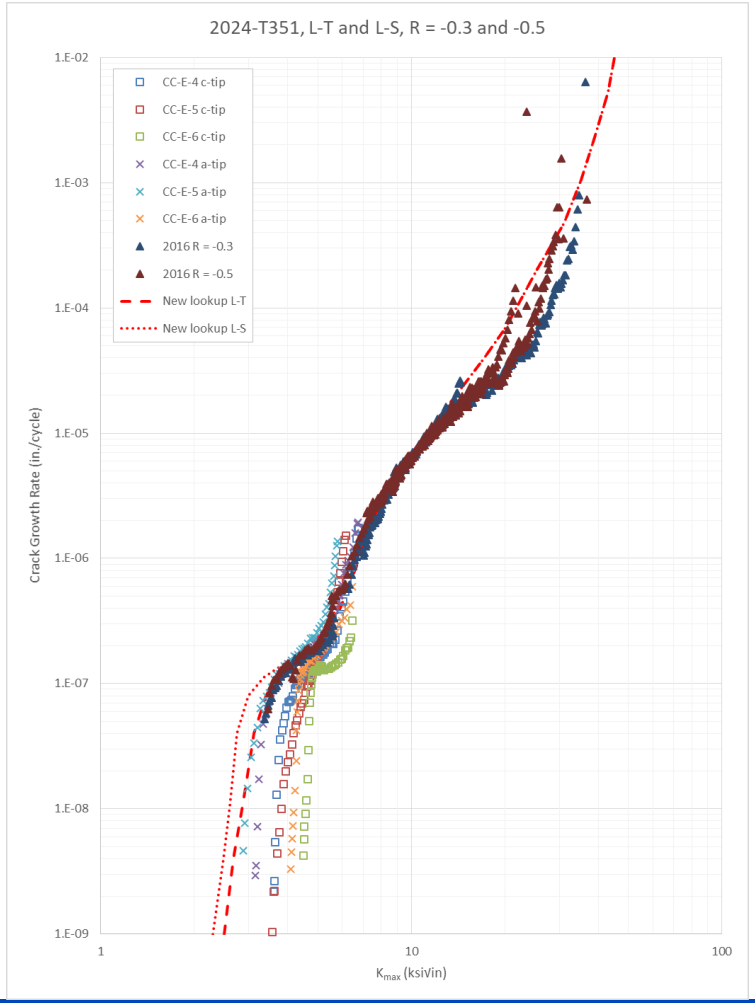
- Load shedding controlled by DCPD
  - $C = -4\ in^{-1}$ $\quad (0.035 < -C\,(K_{max,i} / \sigma_y)^2 < 0.097)$
  - Pre-test assumption of aspect ratios for K input to DCPD
  - Post-test correction of applied K for da/dN-ΔK curves

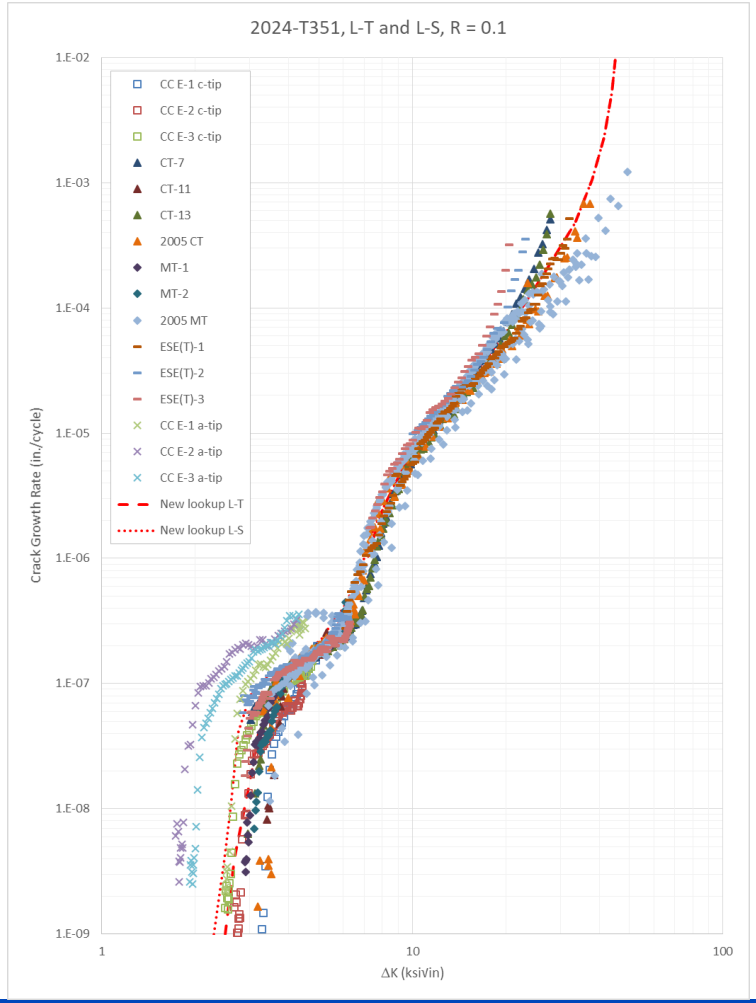
L-T and L-S test results

- Most details shown last year – summary and fits shown here
  - 2024-T351 plate
  - 2024-T3511 extrusion
  - 7075-T651 plate
  - 7175-T74 forging

L-T and L-S test results

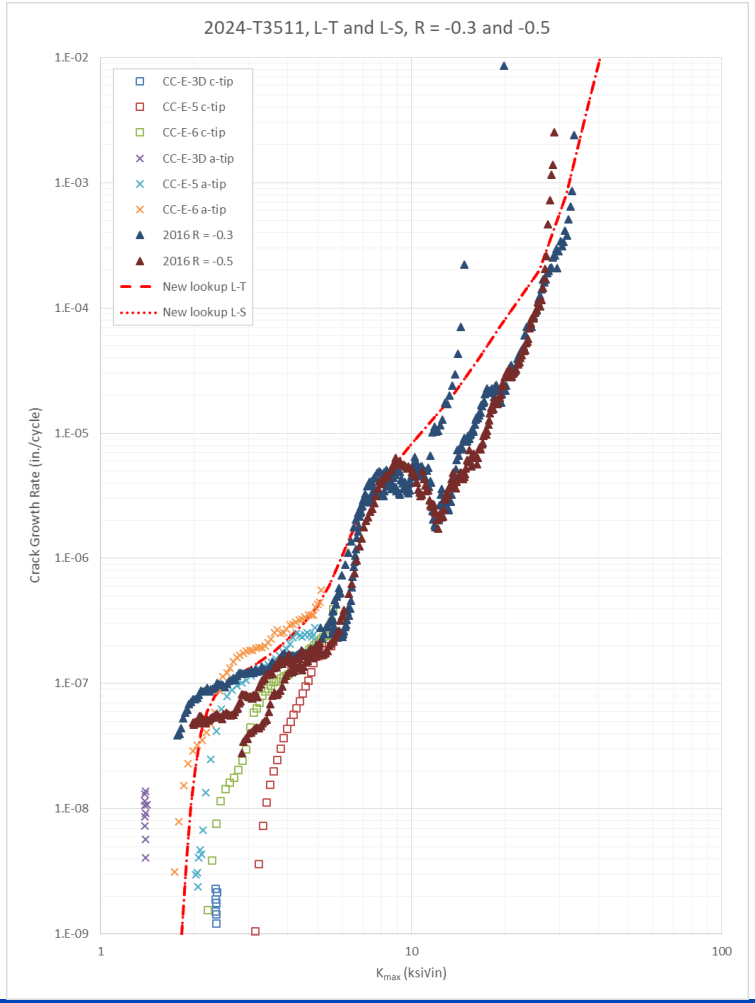
- 2024-T351 – L-S shows faster near-threshold rates

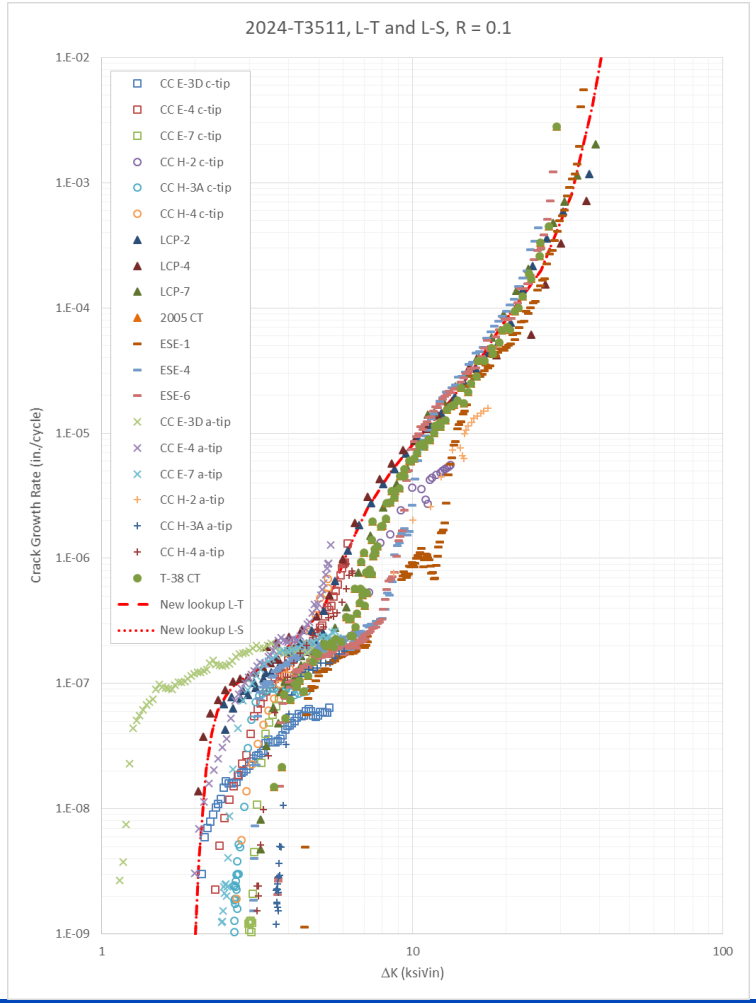




L-T and L-S test results

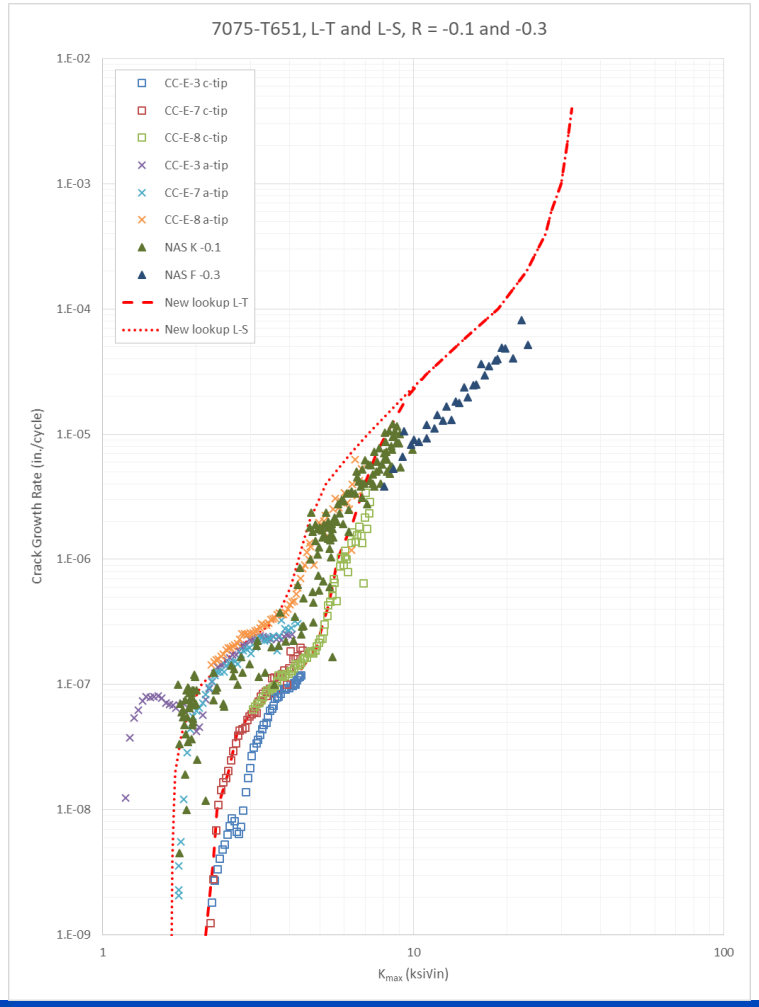
- 2024-T3511 – Difference between L-T and L-S unclear

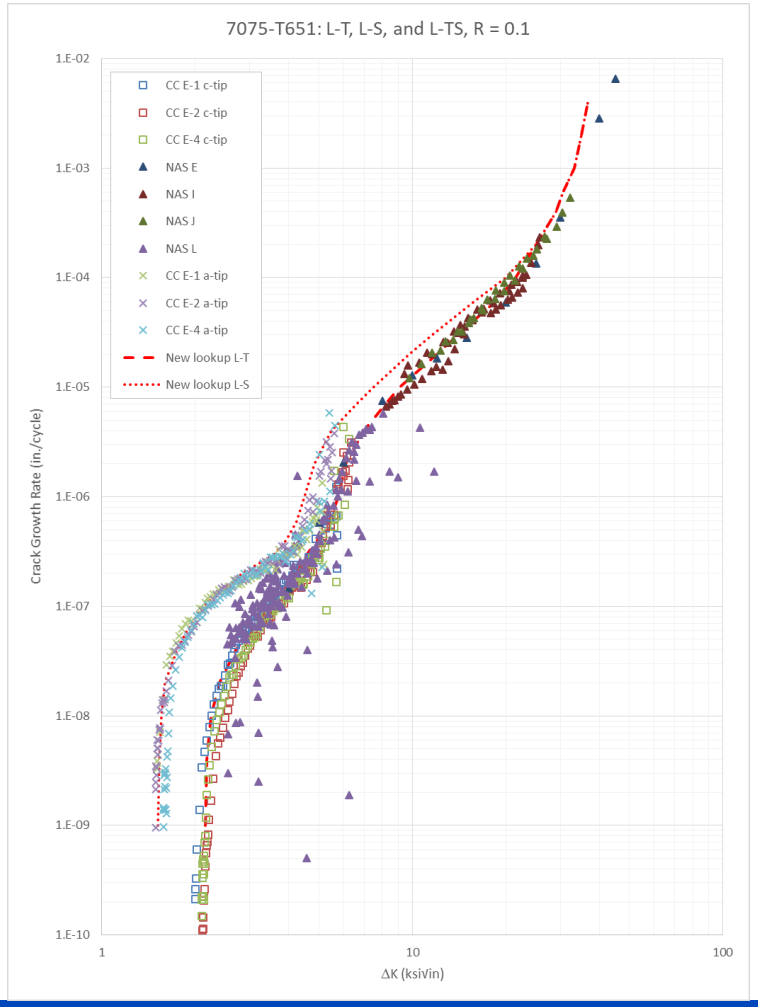




L-T and L-S test results

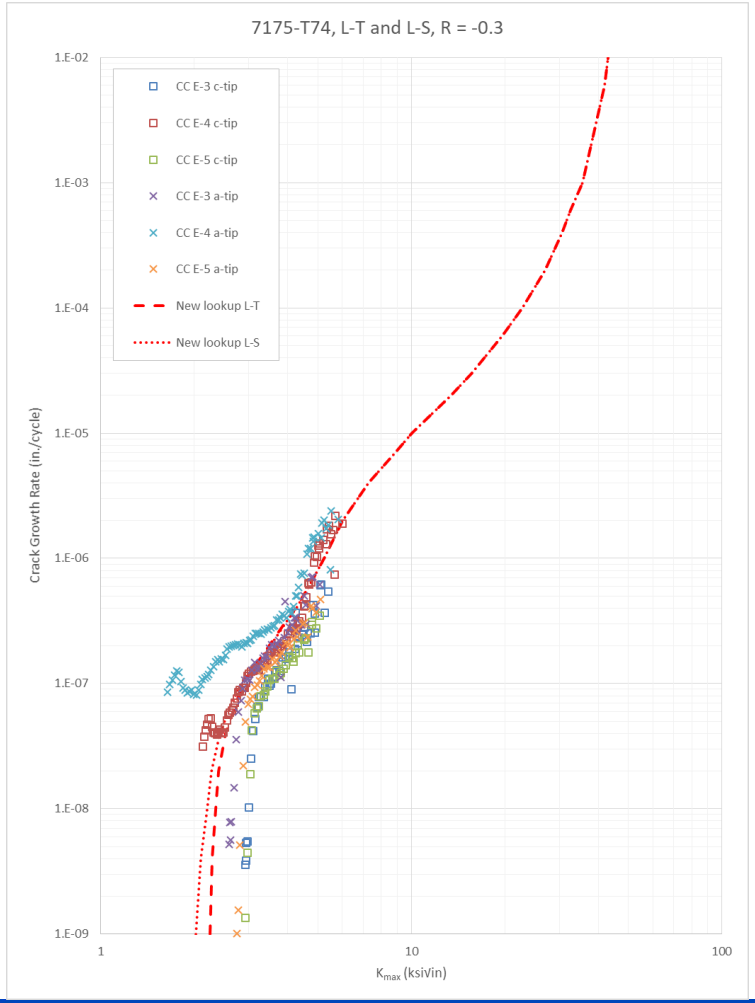
- 7075-T651 – L-S shows faster near-threshold rates

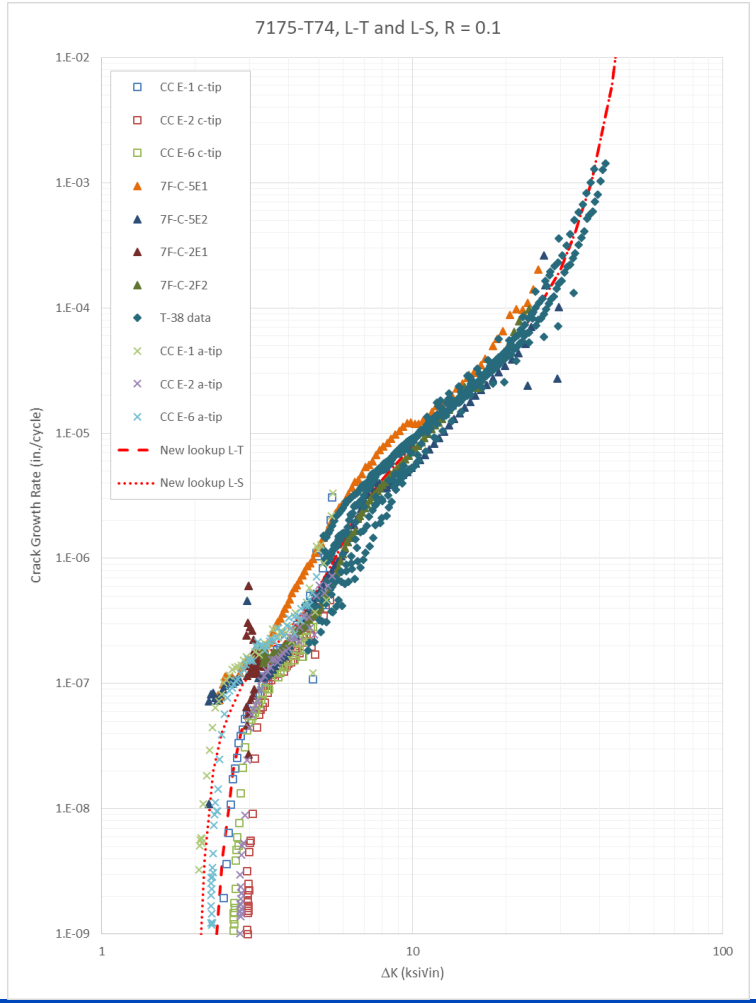




L-T and L-S test results

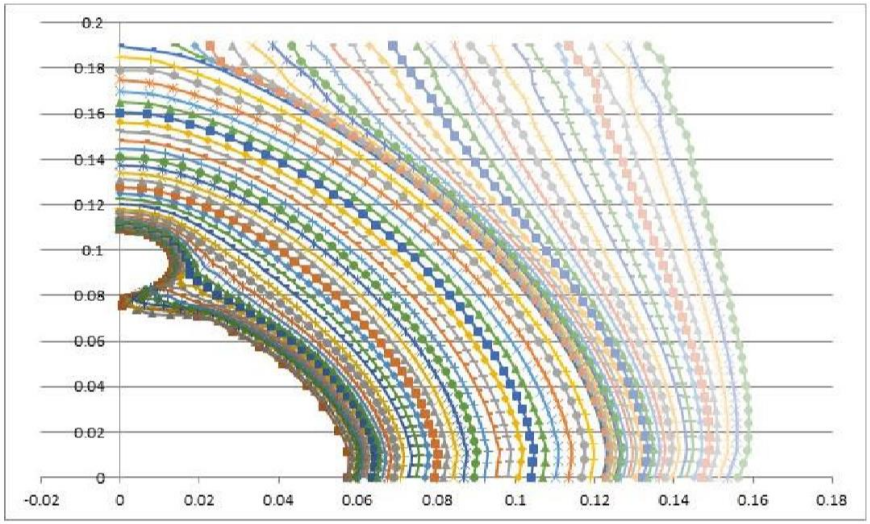
- 7175-T74 – L-S shows faster near-threshold rates





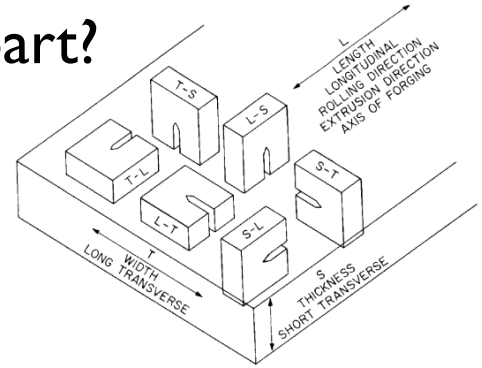
Motivation for diagonal rate testing

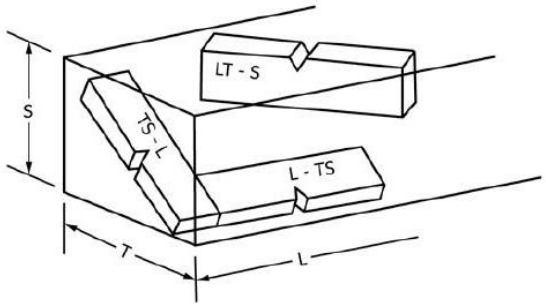
- When performing multipoint analysis, growth is generally not purely L-T or L-S

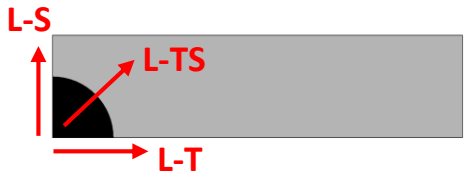


(Ref: Hodges, J., "The Future of BAMF," 2017 AFGROW Users Workshop)

- What growth rates do we use when growing a crack diagonally into a part?

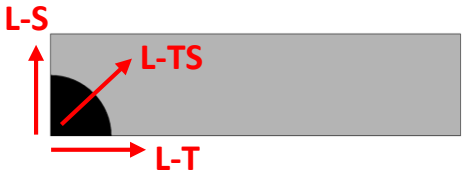


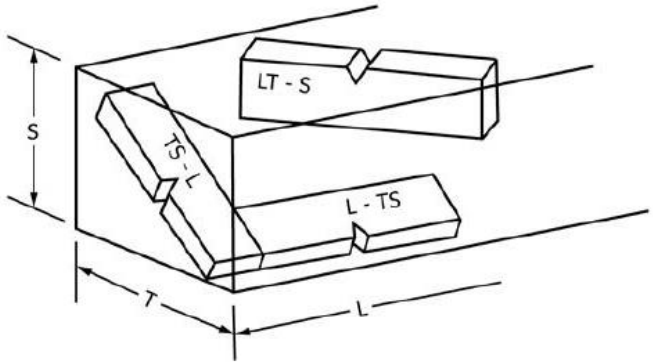


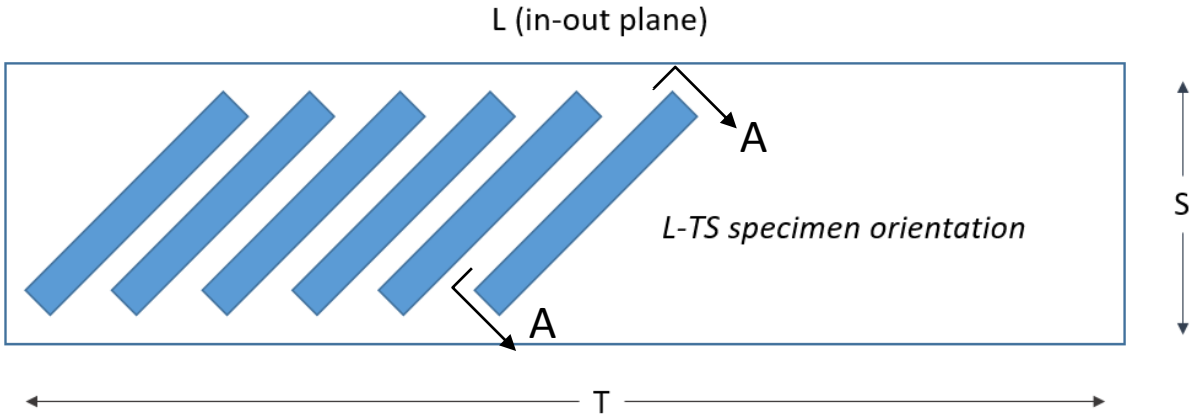


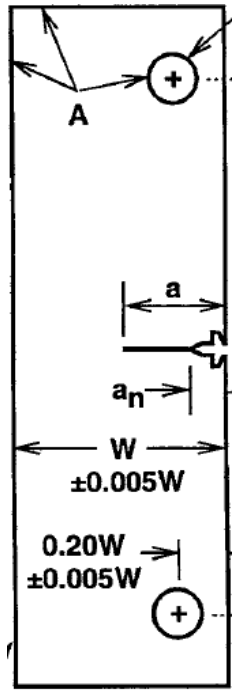
L-TS test procedure

- ESE(T) specimens cut at 45° diagonal from source material
  - ESE(T): Eccentrically-loaded single edge crack tension
- All test procedures follow E647





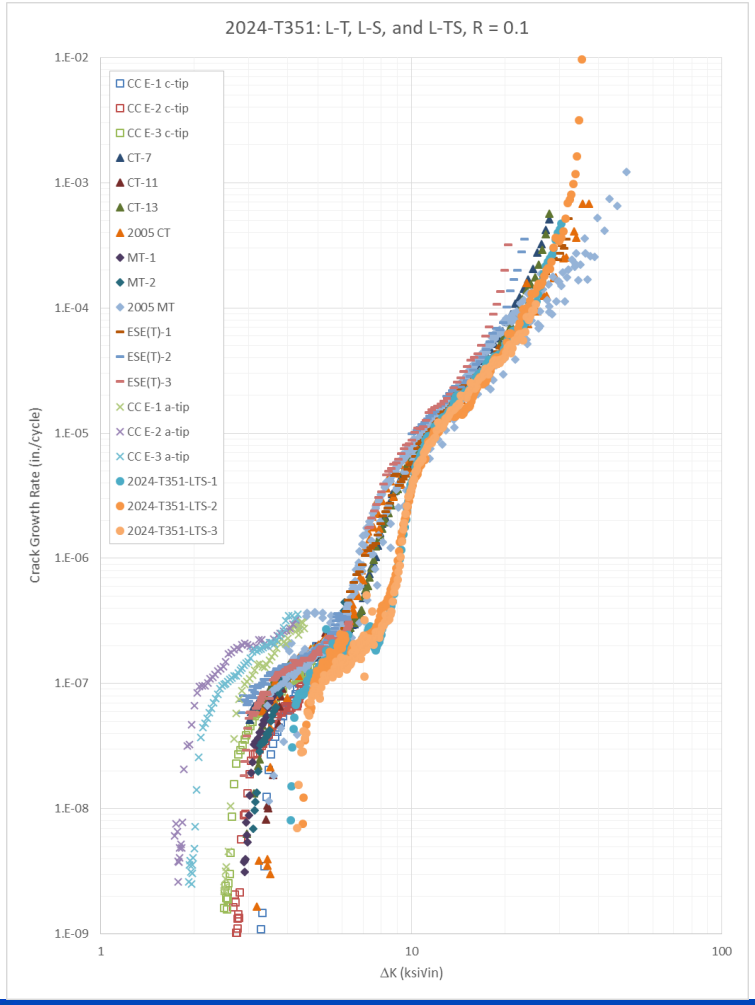


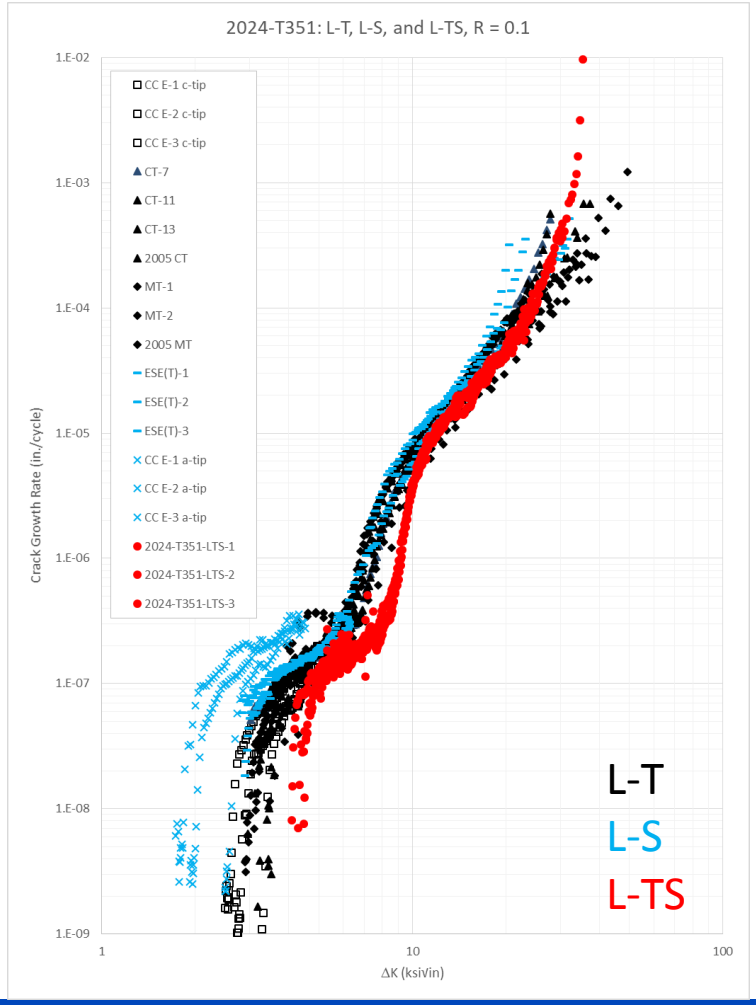


Section A-A
Rotated 45° CW

L-TS test results

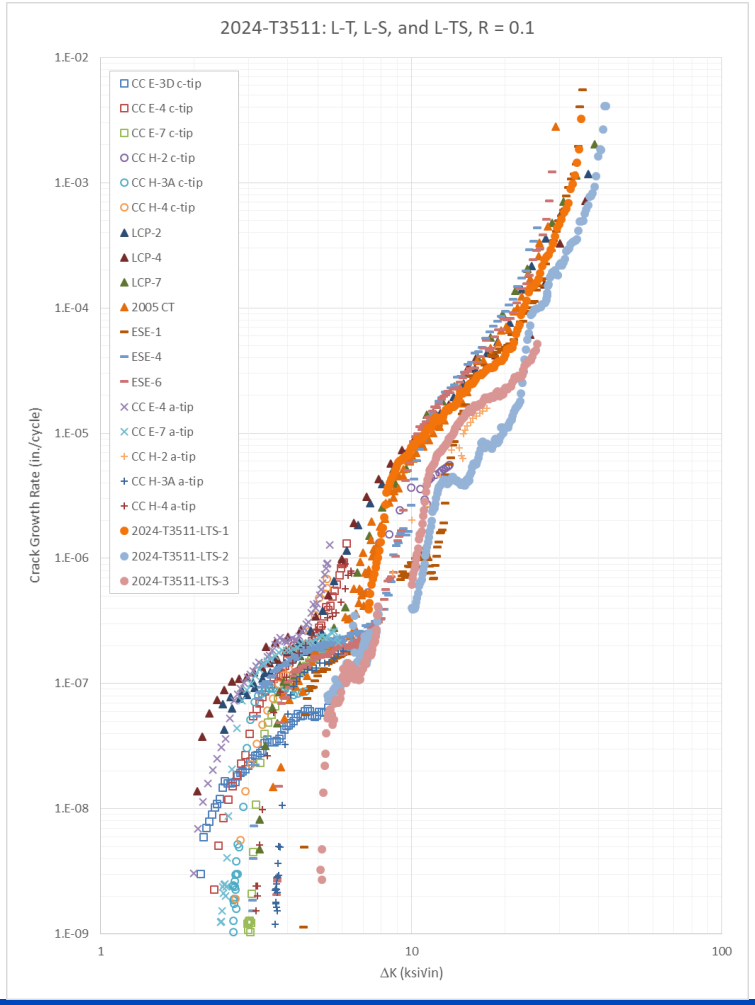
- 2024-T351 – L-TS has slower near-threshold rates

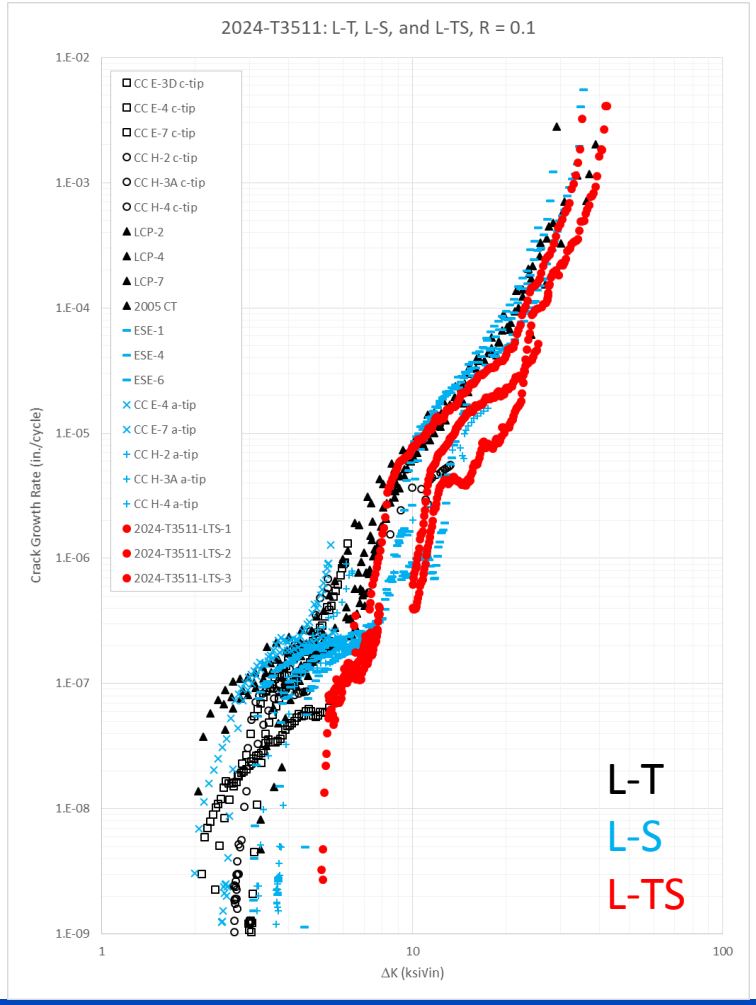




L-TS test results

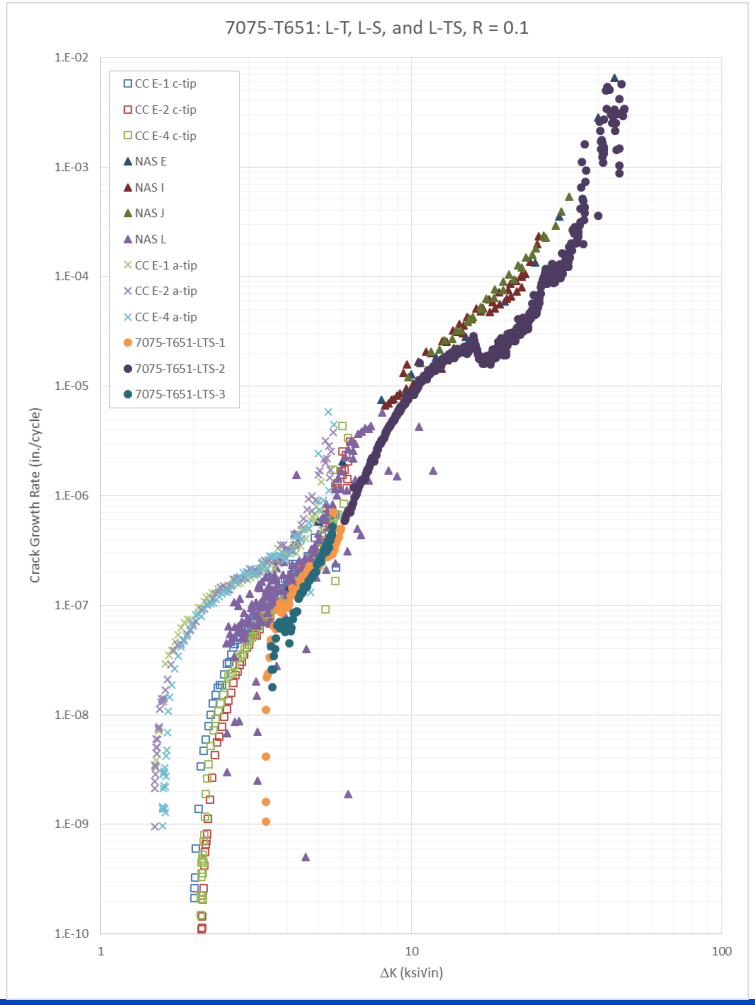
- 2024-T3511 – L-TS has slower near-threshold rates

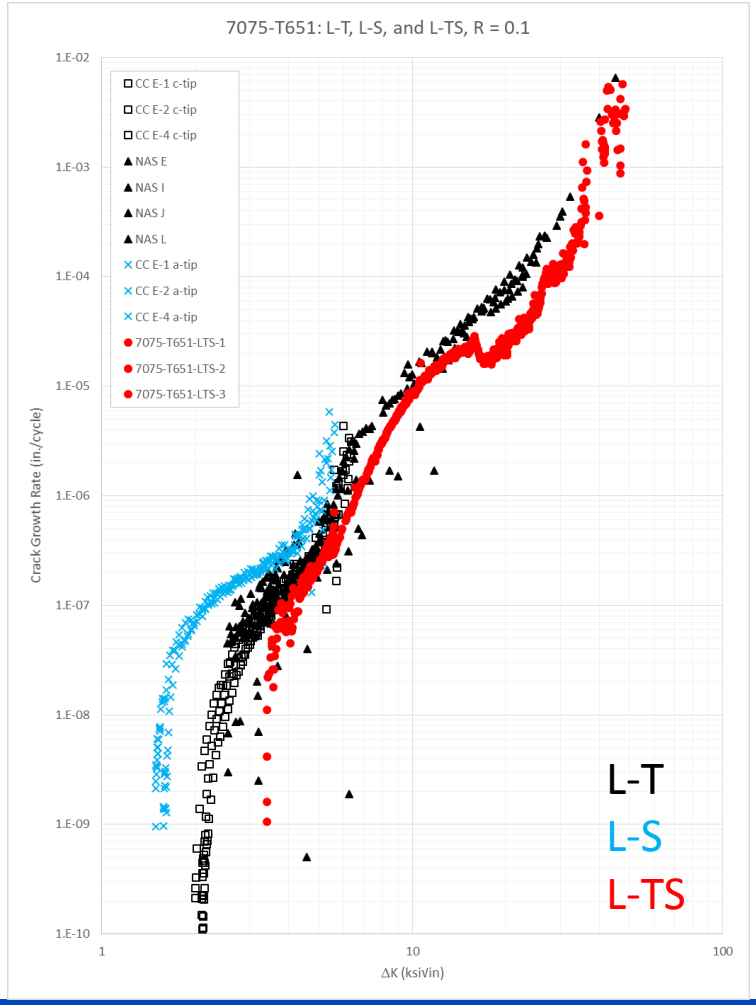




L-TS test results

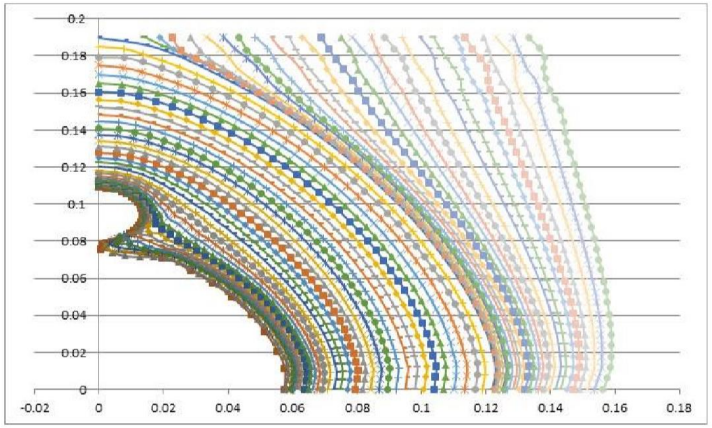
- 7075-T651 – L-TS has slower near-threshold rates

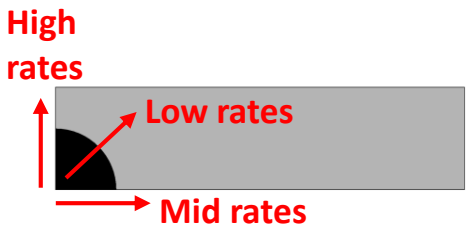




Impact on analysis

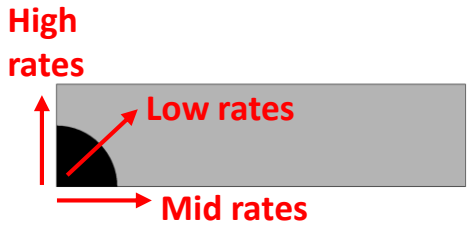
- Two-dimensional analysis (a-tip and c-tip)
  - Analytical aspect ratios will increase
    - Example 7075-T651 analysis: Final a/c = 1.89 vs. 1.52
  - Analytical transition will happen sooner, decreasing lives
    - Example 7075-T651 analysis: Life = 45K cycles vs. 47K cycles
- Multipoint analysis
  - What growth rates do we use when growing a crack diagonally?
    - Prior desire was to interpolate between directional rates

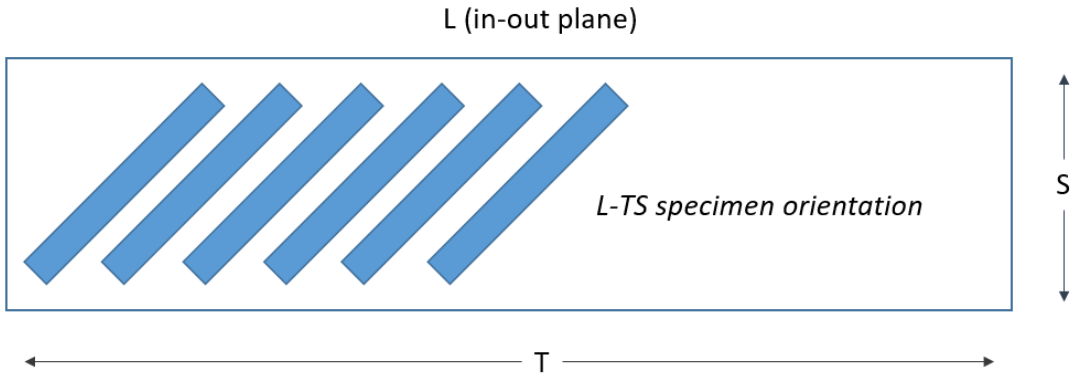




Remaining issues

- Why do the cracks consistently grow at an angle?
  - Confirmation of faster L-S growth?





- Are the slow L-TS rates really what we should be using?
  - Do part-through crack constraint differences impact rates?
    - Determine L-TS rates from corner crack tests?

Conclusions

- Through crack and corner crack tests give consistent results for L-T and L-S rates
  - L-S rates tend to be slightly higher near-threshold than L-T
- L-TS rates appear to be slower than L-T and L-S
  - Complicates implementation of multipoint analysis with directional rates
- Confirmation of L-TS results in corner cracks should be considered