Fatigue crack growth rate testing to characterize diagonal (L-TS) growth

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Luciano Smith and James Feiger
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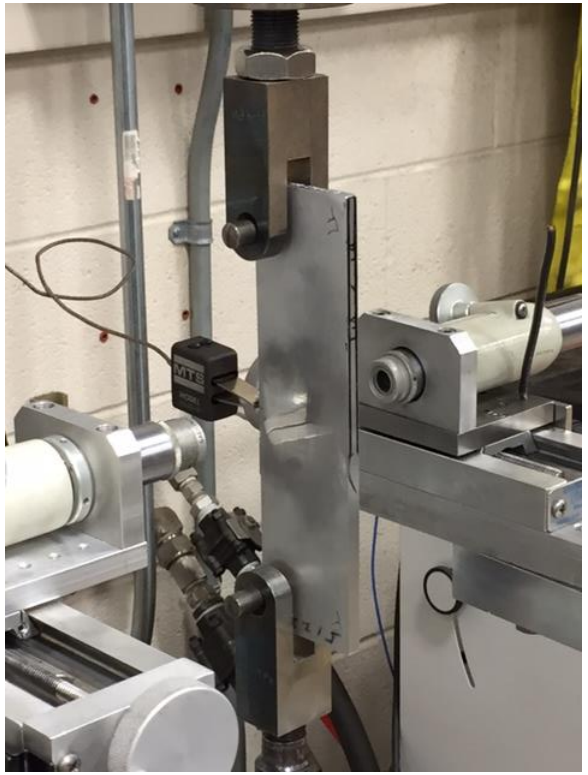
Introduction

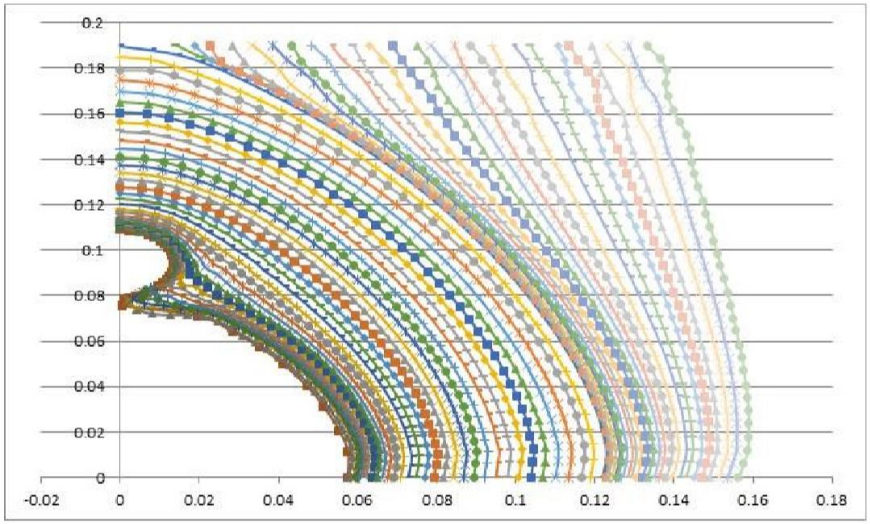
- Thanks to Mark Thomsen, Jacob Warner, and Kaylon Anderson from A-10 ASIP

- Motivation for testing for growth rates in different directions
- Previous testing
  - L-T and L-S
  - L-TS
- Corner crack testing for L-TS direction
- Impact on analysis



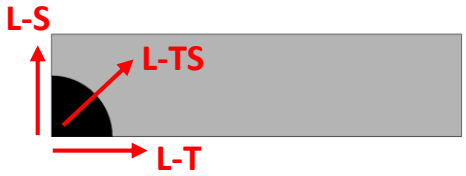
Motivation for testing in different directions

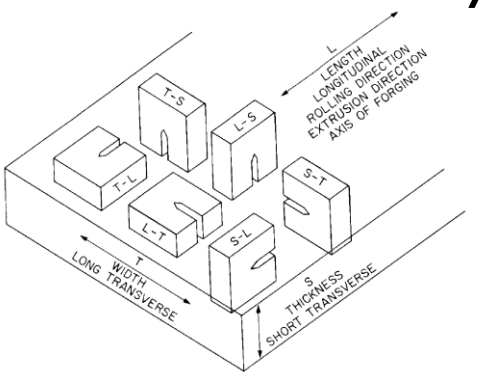
- When performing multipoint analysis, growth is generally not purely L-T or L-S

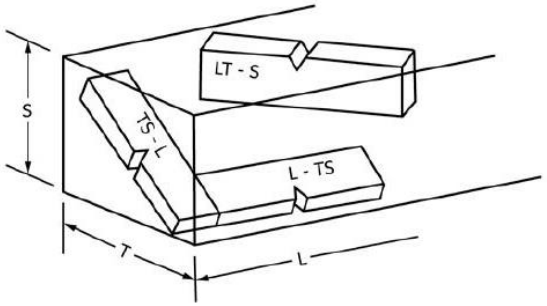


(Ref: Hodges, J., "The Future of BAMF," 2017 AFGROW Users Workshop)

- What growth rates do we use when analytically growing a crack like this?

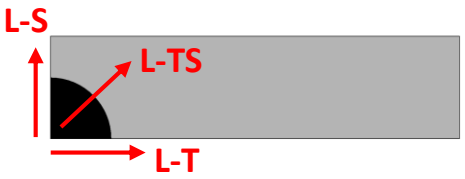


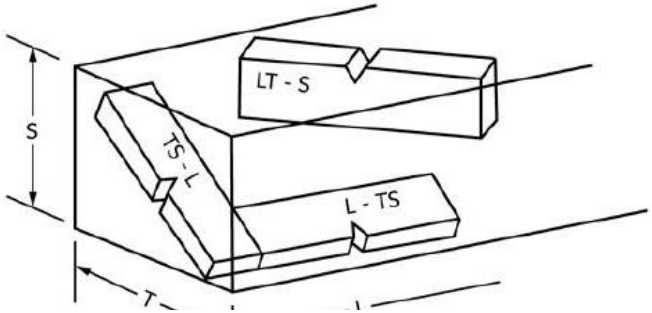




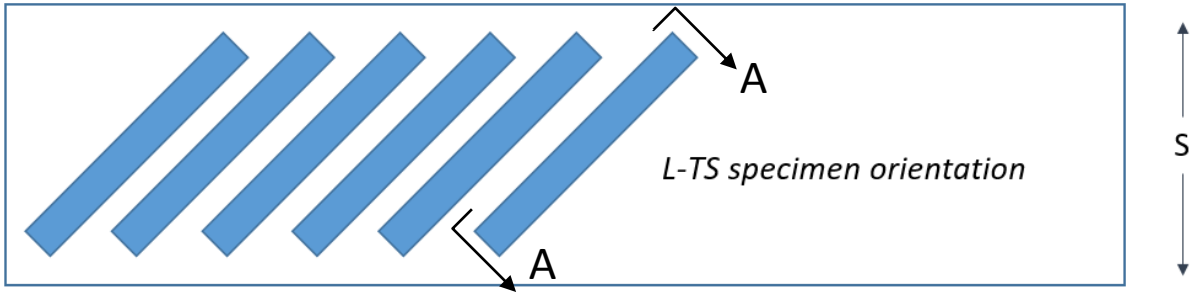
L-TS through crack test procedure

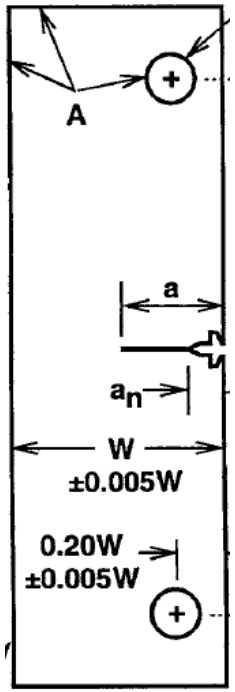
- ESE(T) specimens cut at 45° diagonal from source material
  - ESE(T): Eccentrically-loaded single edge crack tension
  - Materials: 2024-T351, 2024-T3511, and 7075-T651
- All test procedures follow ASTM E647





L (in-out plane)



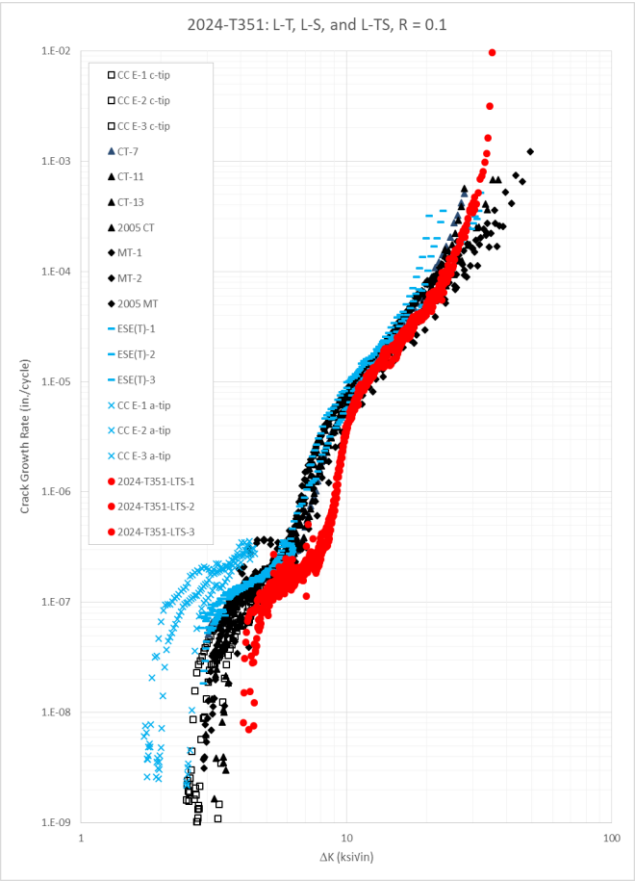


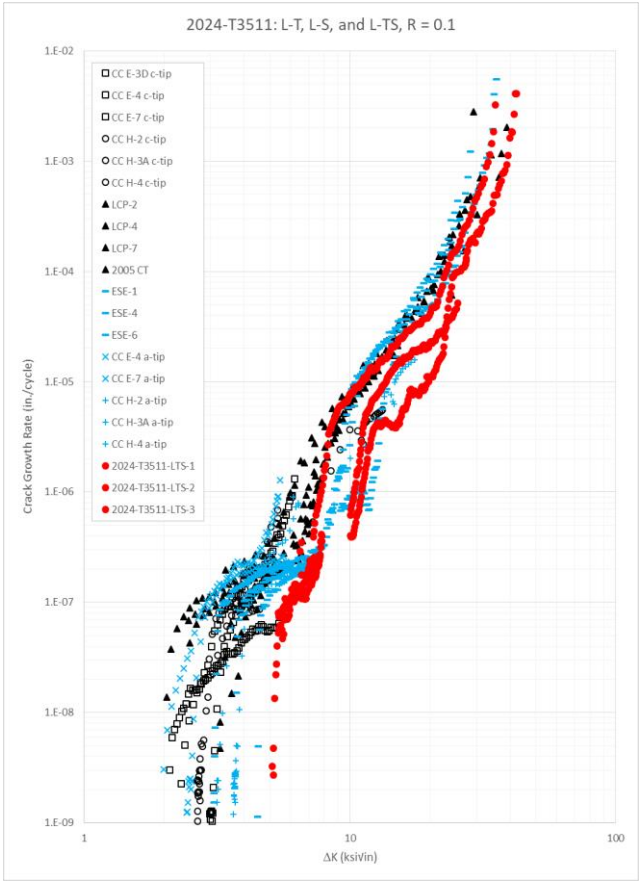
Section A-A
Rotated 45° CW

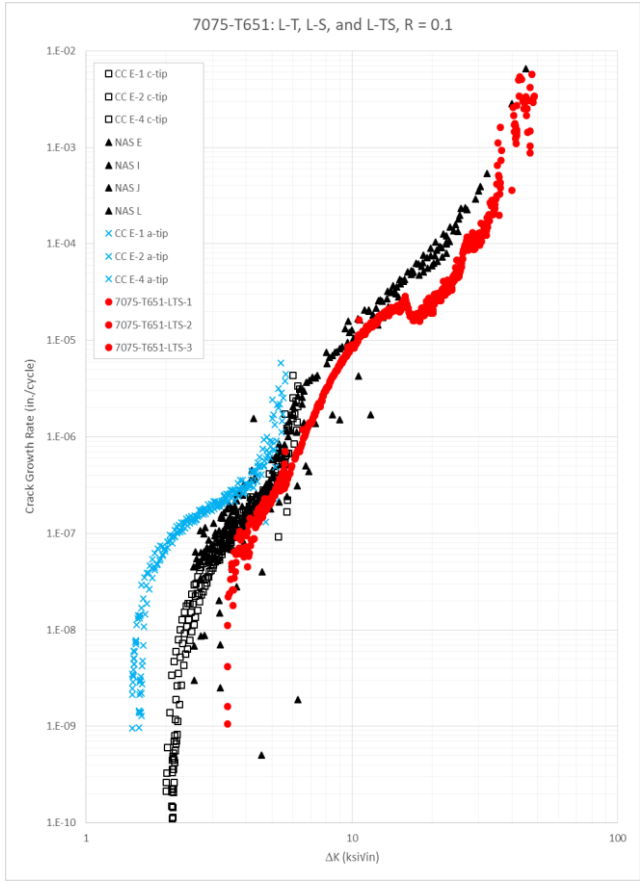
L-TS through crack results

L-T
L-S
L-TS

- L-TS showed slowest near-threshold rates

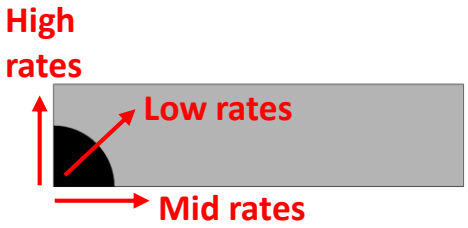






Conclusions after through crack tests

- 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 slower than L-T and L-S
  - Complicates implementation of multipoint analysis with directional rates

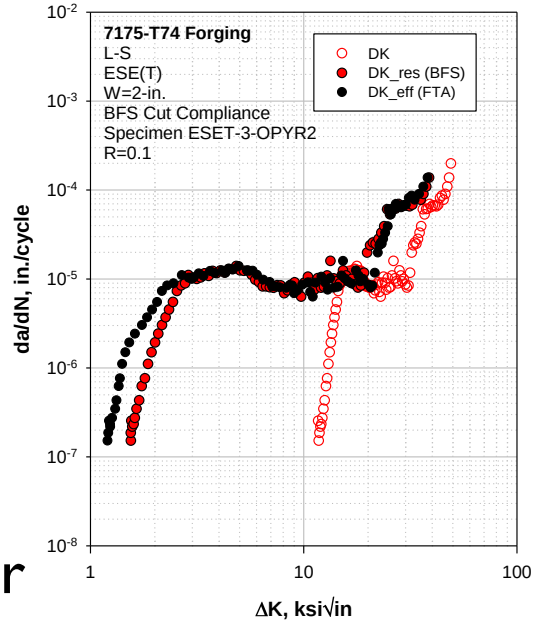


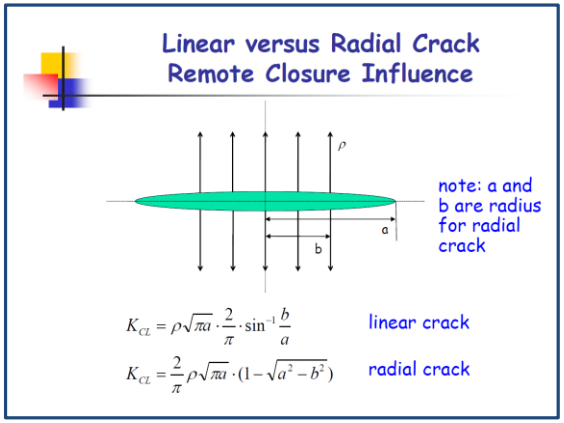
- Are the slow L-TS rates really what we should be using?
  - Do part-through crack constraint differences impact rates?

➢ Confirmation of results in corner cracks should be considered

Benefits of corner crack testing

- Ability to gather L-T and L-S growth rate data in one test
- Specimens can be cut from thin material
  - Helps minimize residual stresses
- The standard ASTM E647 specimens are through cracks and considered "long" cracks
- 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

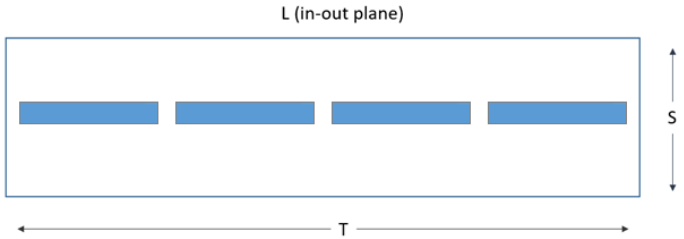


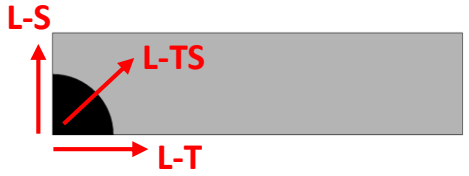


(Ref: K. Donald, ASTM E08.06.06 meeting minutes, November 15, 2016)

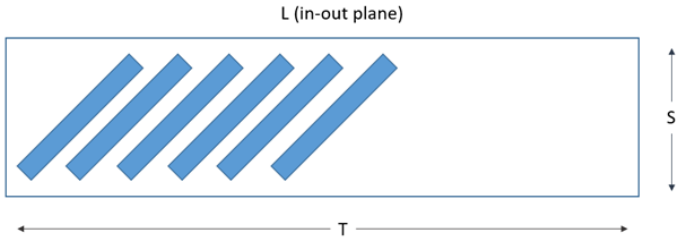
L-TS corner crack test procedure

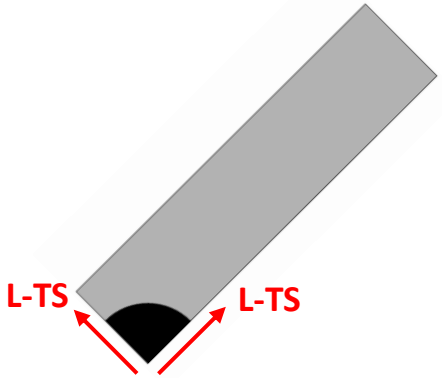
- Two approaches used to cut edge corner cracked specimens
  - Some specimens cut straight along source material surface
    - Marker bands (R variation) used to determine L-TS crack lengths





  - Some specimens cut at 45° diagonal from source material

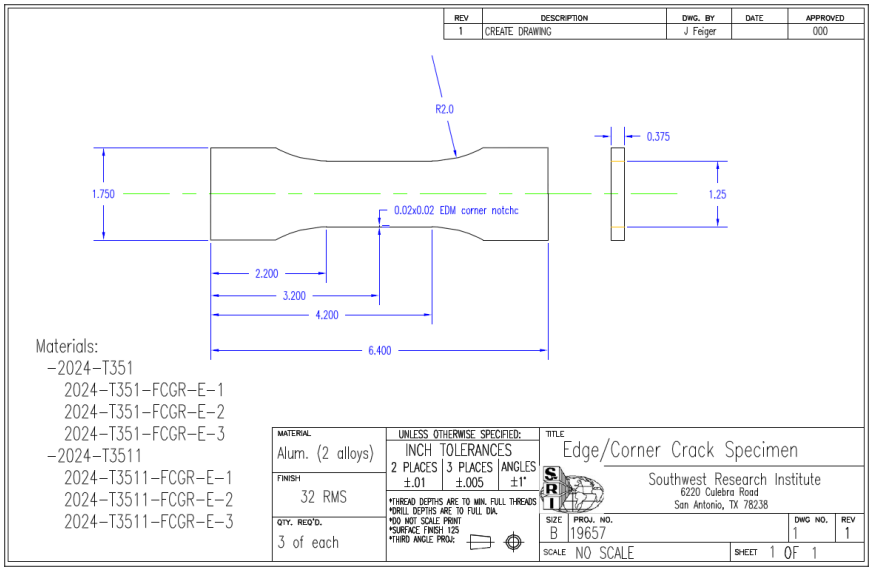




- All test procedures follow ASTM E647

L-TS corner crack test procedure

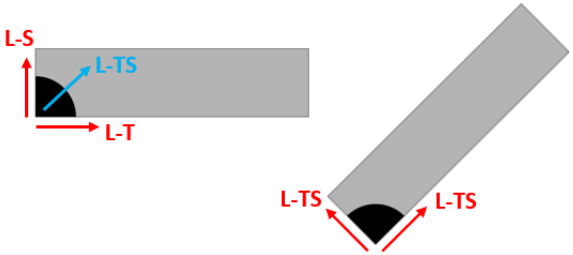
- Materials: 2024-T351 and 7075-T651



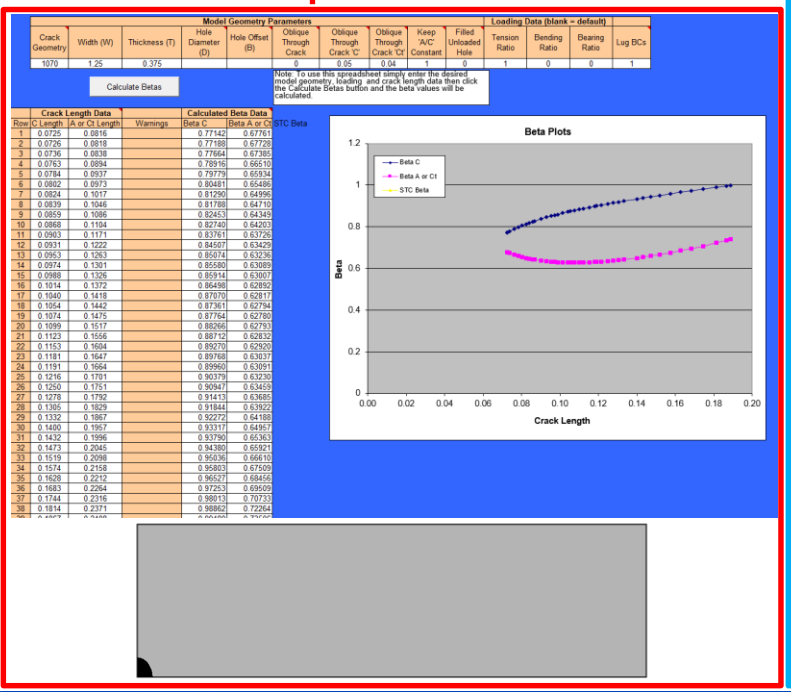
- Load shedding controlled by DCPD
  - C = -4 in^{-1} $(0.035 < -C\,(K_{max,i} / \sigma_y)^2 < 0.097)$
  - Pre-test assumption of aspect ratios for K input to DCPD
  - Post-test correction of applied K for da/dN-ΔK curves

L-TS corner crack test procedure

- Stress intensity calculation for da/dN vs ΔK



Crack tip locations



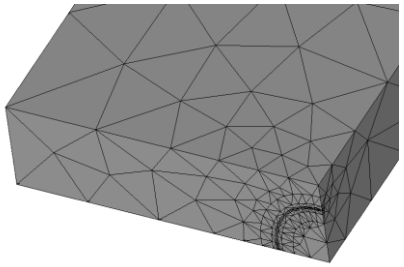
Model Geometry Parameters										Loading Data (blank = default)			
Crack Geometry	Width (W)	Thickness (T)	Hole Diameter (D)	Hole Offset (B)	Oblique Through Crack	Oblique Through Crack 'C'	Oblique Through Crack 'Ct'	Keep 'A/C' Constant	Filled Unloaded Hole	Tension Ratio	Bending Ratio	Bearing Ratio	Lug BCs
1070	1.25	0.375			0	0.05	0.04	1	0	1	0	0	1

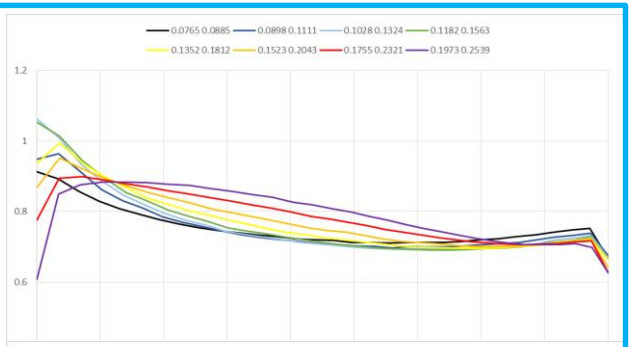
Calculate Betas

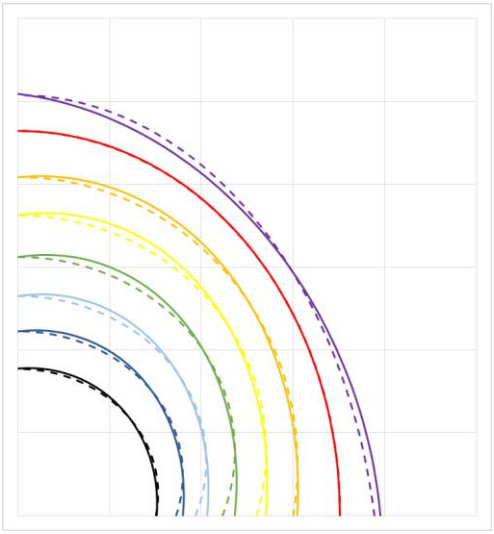
Note: To use this spreadsheet simply enter the desired model geometry, loading and crack length data then click the Calculate Betas button and the beta values will be calculated.

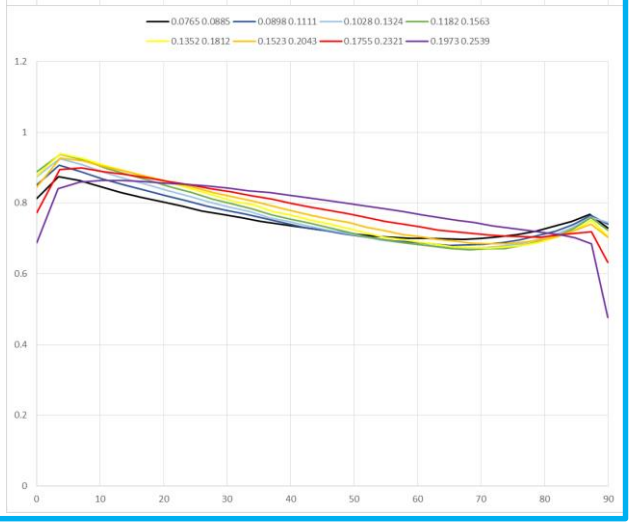
	Crack Length Data			Calculated Beta Data		
Row	C Length	A or Ct Length	Warnings	Beta C	Beta A or Ct	STC Beta
1	0.0725	0.0816		0.77142	0.67761	
2	0.0726	0.0818		0.77188	0.67729	
3	0.0736	0.0838		0.77664	0.67383	
4	0.0763	0.0894		0.78916	0.66510	
5	0.0784	0.0937		0.79779	0.65934	
6	0.0802	0.0973		0.80481	0.65486	
7	0.0824	0.1017		0.81290	0.64996	
8	0.0839	0.1046		0.81788	0.64710	
9	0.0859	0.1086		0.82453	0.64349	
10	0.0868	0.1104		0.82740	0.64203	
11	0.0903	0.1171		0.83761	0.63726	
12	0.0931	0.1222		0.84507	0.63429	
13	0.0953	0.1263		0.85074	0.63238	
14	0.0974	0.1301		0.85580	0.63089	
15	0.0988	0.1326		0.85914	0.63007	
16	0.1014	0.1372		0.86498	0.62892	
17	0.1040	0.1418		0.87070	0.62817	
18	0.1054	0.1442		0.87361	0.62794	
19	0.1074	0.1475		0.87764	0.62780	
20	0.1099	0.1517		0.88266	0.62793	
21	0.1123	0.1556		0.88712	0.62832	
22	0.1153	0.1604		0.89270	0.62920	
23	0.1181	0.1647		0.89768	0.63037	
24	0.1191	0.1664		0.89960	0.63091	
25	0.1216	0.1701		0.90379	0.63230	
26	0.1250	0.1751		0.90947	0.63459	
27	0.1278	0.1792		0.91413	0.63685	
28	0.1305	0.1829		0.91844	0.63927	
29	0.1332	0.1867		0.92272	0.64188	
30	0.1400	0.1957		0.93317	0.64957	
31	0.1432	0.1996		0.93790	0.65363	
32	0.1473	0.2045		0.94380	0.65921	
33	0.1519	0.2098		0.95036	0.66610	
34	0.1574	0.2158		0.95803	0.67509	
35	0.1628	0.2212		0.96527	0.68466	
36	0.1683	0.2264		0.97253	0.69509	
37	0.1744	0.2316		0.98013	0.70733	
38	0.1814	0.2371		0.98862	0.72264	

Embedded locations





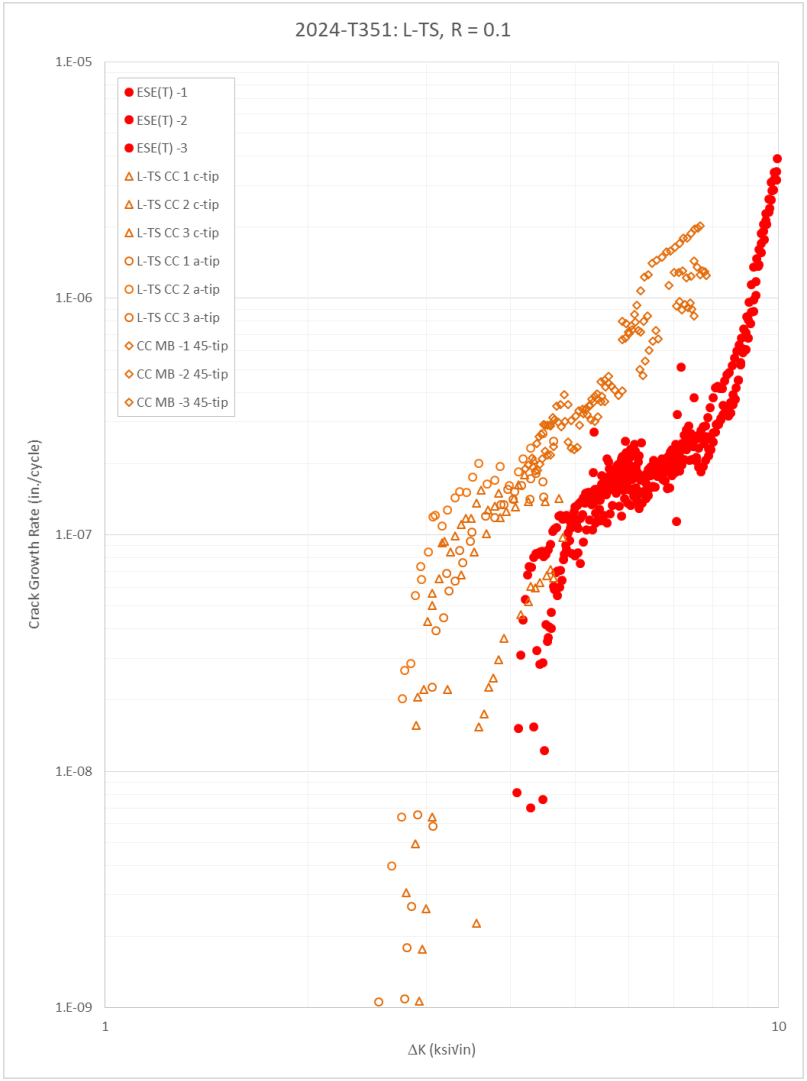


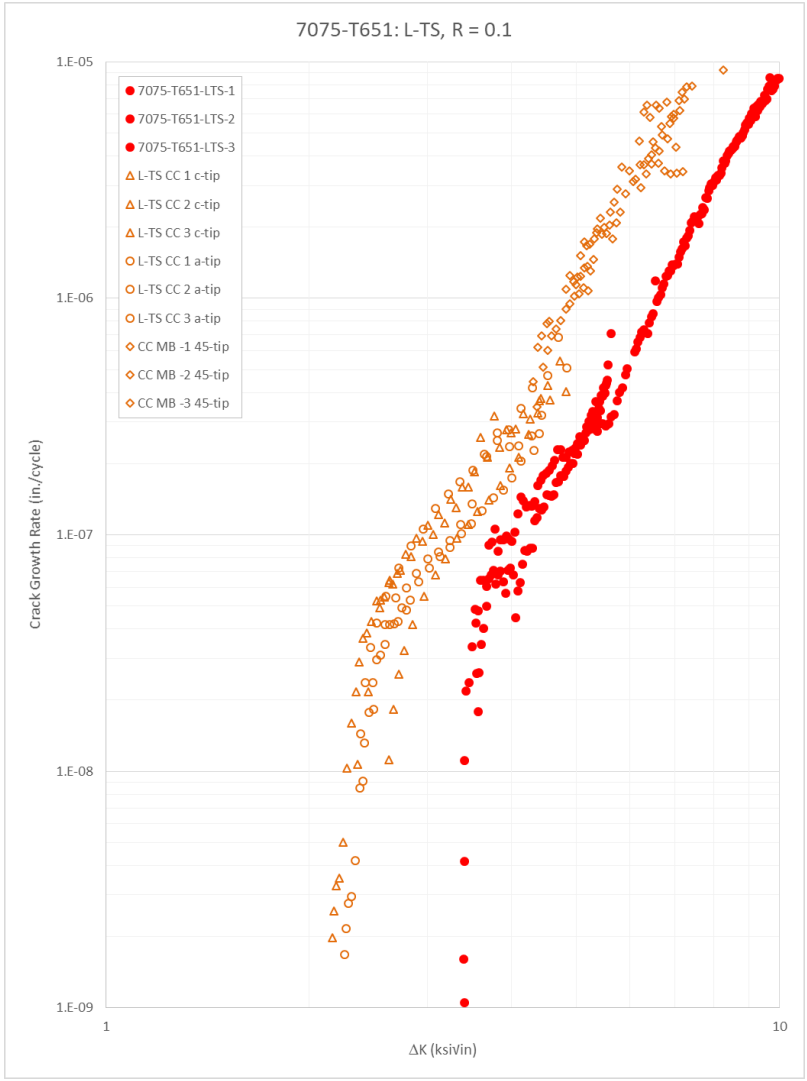


L-TS corner crack test results

Corner crack vs through crack

L-TS CC
L-TS ESE(T)

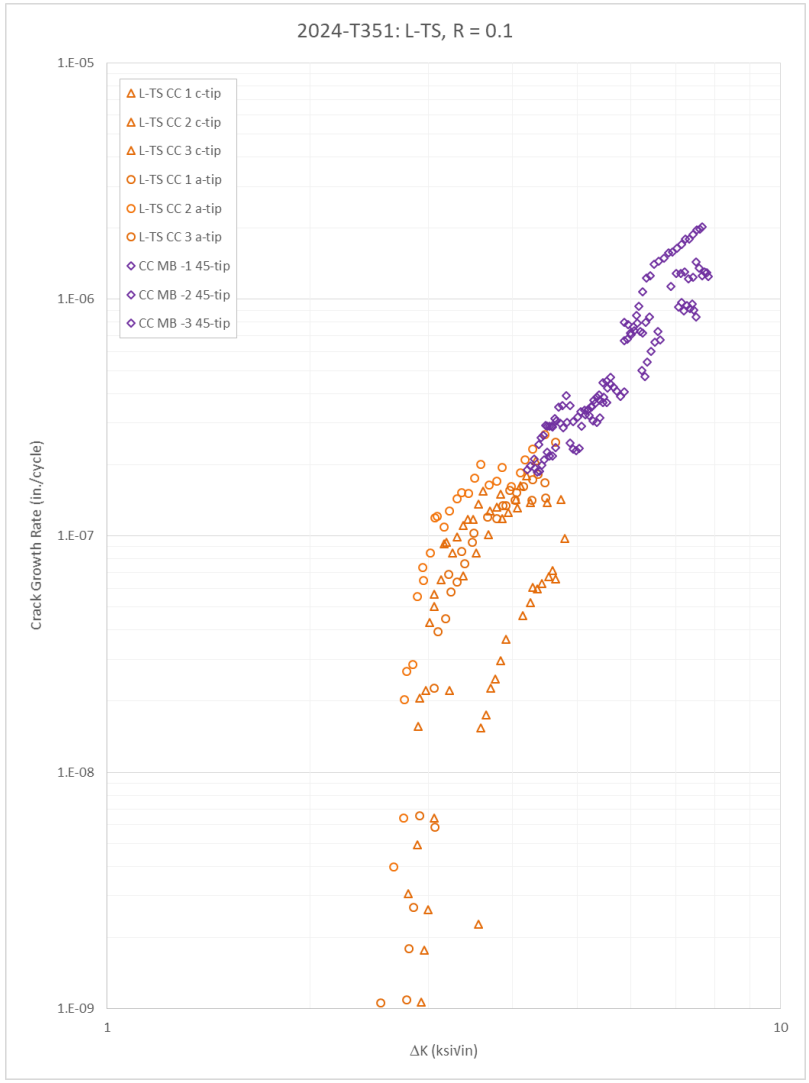


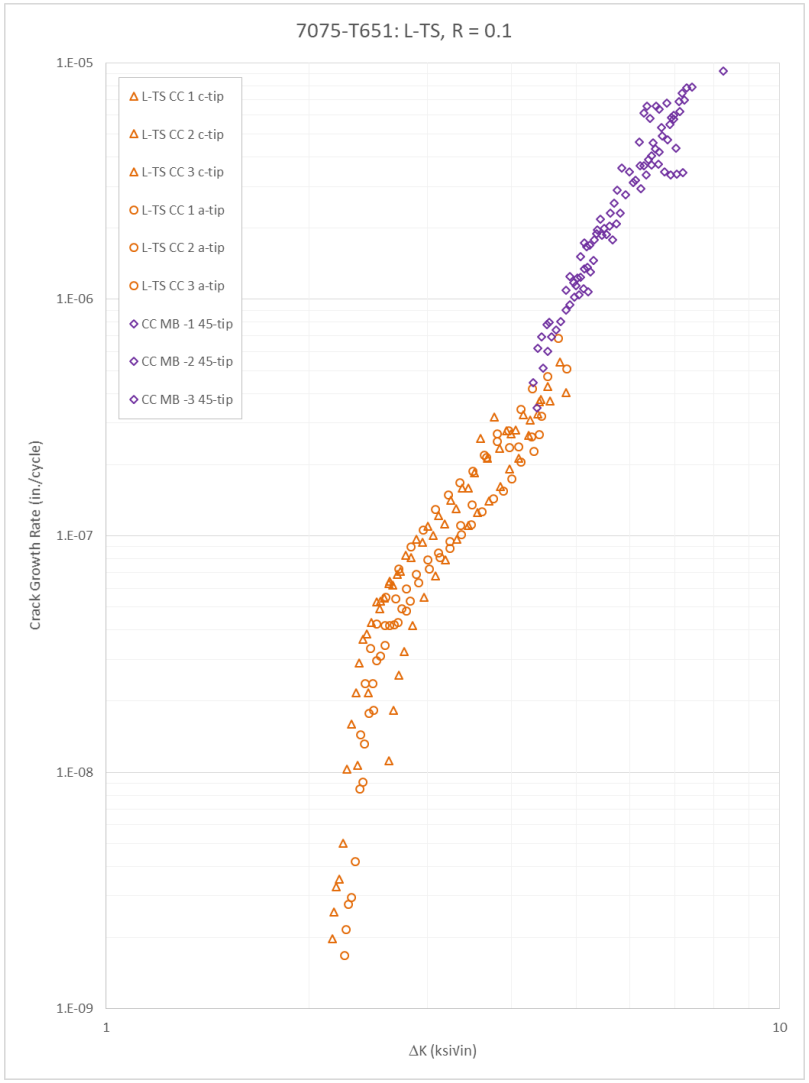


L-TS corner crack test results

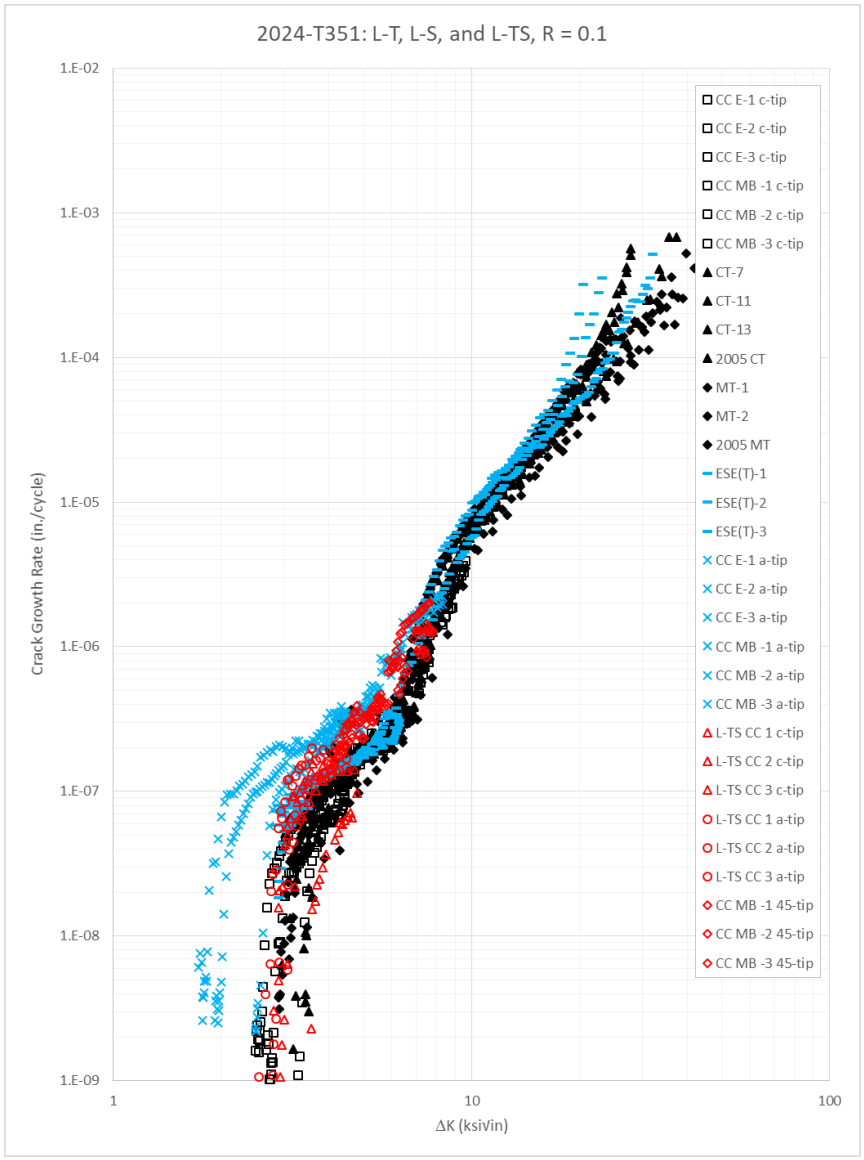
Corner crack surface vs embedded

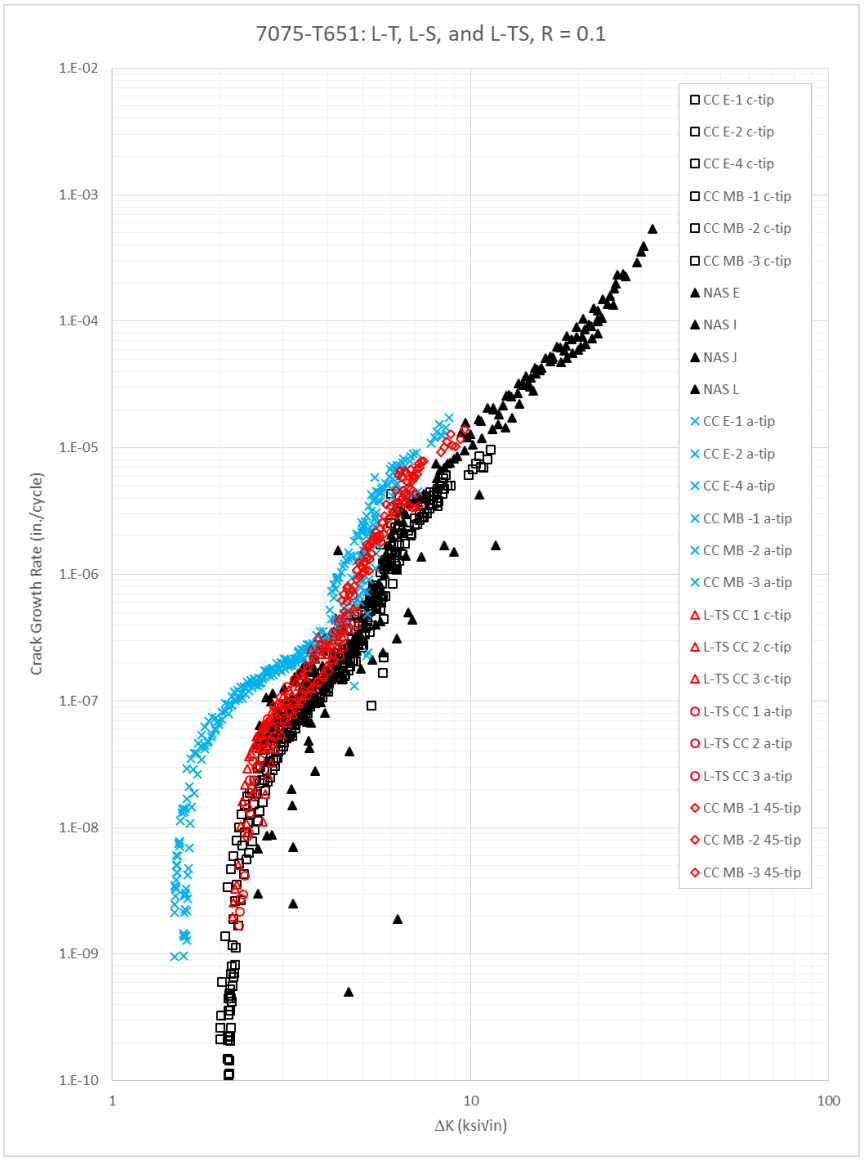
Surface
Embedded





L-TS corner crack test results





L-T
L-S
L-TS

Conclusions

- Specimen geometry shows a significant impact on rates
  - Corner crack specimen more representative of expected rates than through crack specimens
- Initial question:
  - What growth rates do we use when growing a crack diagonally?
  - ➢ For these materials and stress ratios, diagonal crack growth should use rates above but close to the L-T surface rates