

Analysis of Constant Amplitude Countersunk Hole Testing

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Presentation By:

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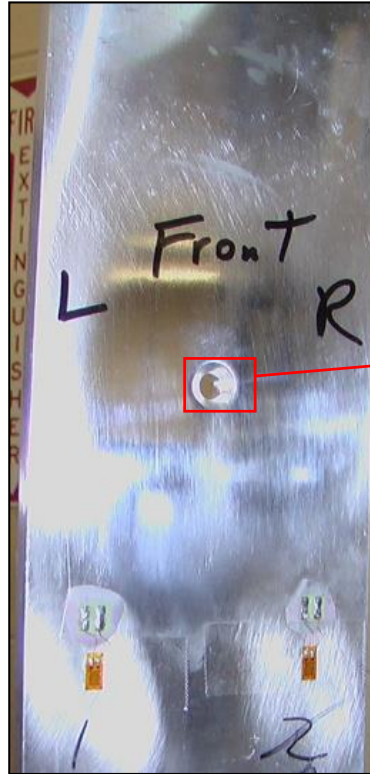
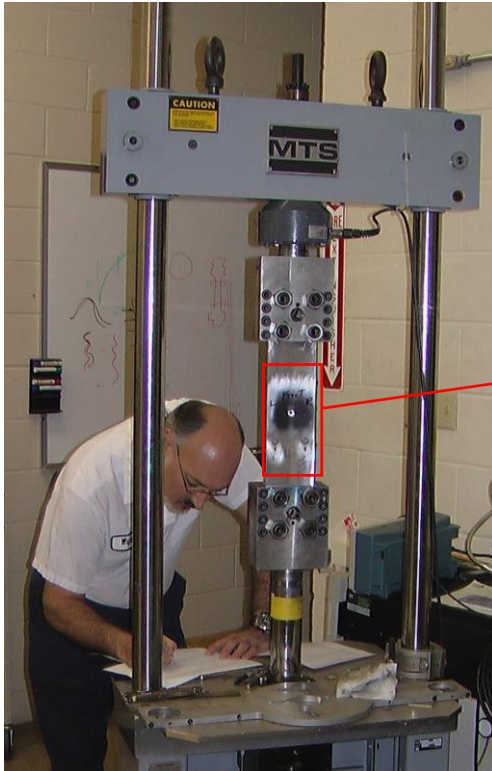
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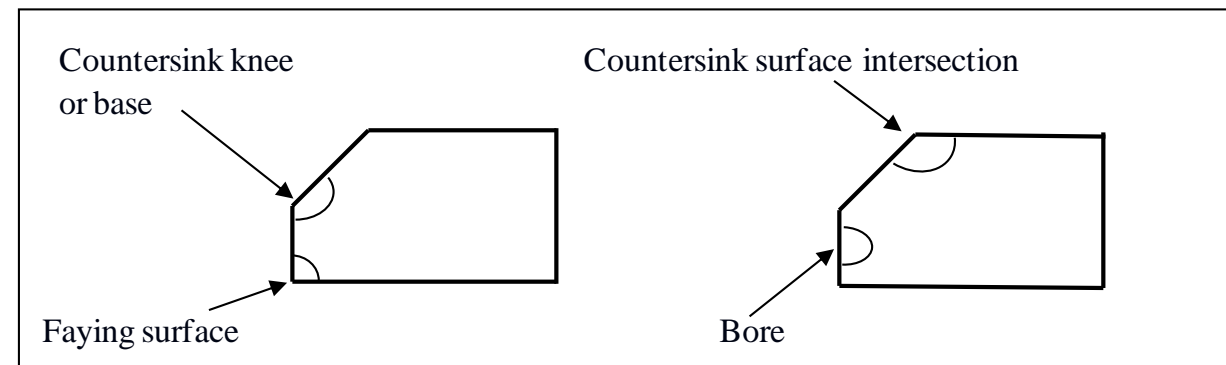
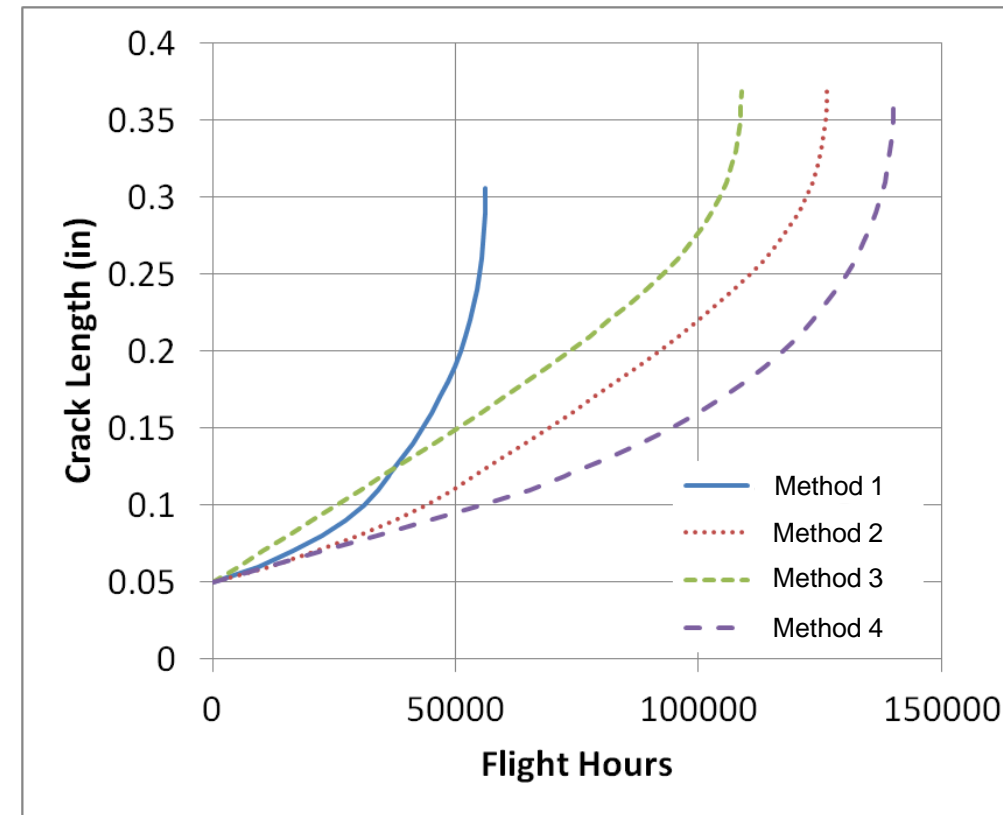
What's the point?

- Test program was put together in 2017 to validate the AFGROW v5.3 newly implemented countersink (CS) hole advanced models
 - Geometry: 7 different countersink geometries, spanning the solution space
 - Loading: Constant amplitude $R=0.1$, Max stress = 8ksi
- Countersink K solutions were developed in 2011 (J. Cronenburger)



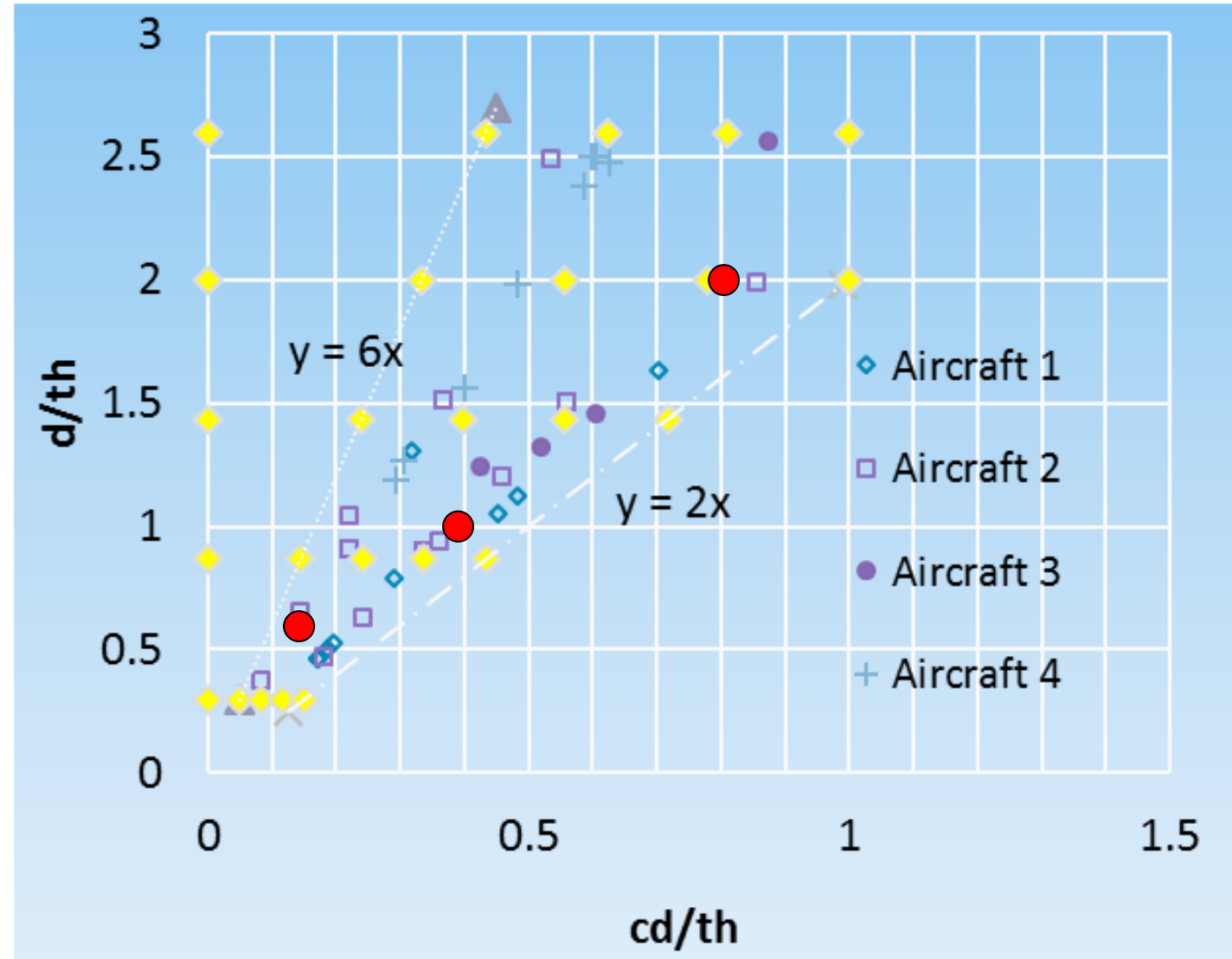
2011 Testing: Background

- Literature review revealed:
 - Limited CS research
 - Hard to apply results
 - Often gaps in the solution space
- Different methods may produce different results
- There was no standardized approach for evaluating CS crack growth
- Different analysis techniques:
 - 'rules of thumb' produce different results, not validated
 - Detailed FEA to obtain Ks
 - Time consuming to build
 - Requires special training
- Four possible crack initiation locations
 - Knee or base of CS has the highest stresses for remote tension loading
 - Only CS knee was evaluated

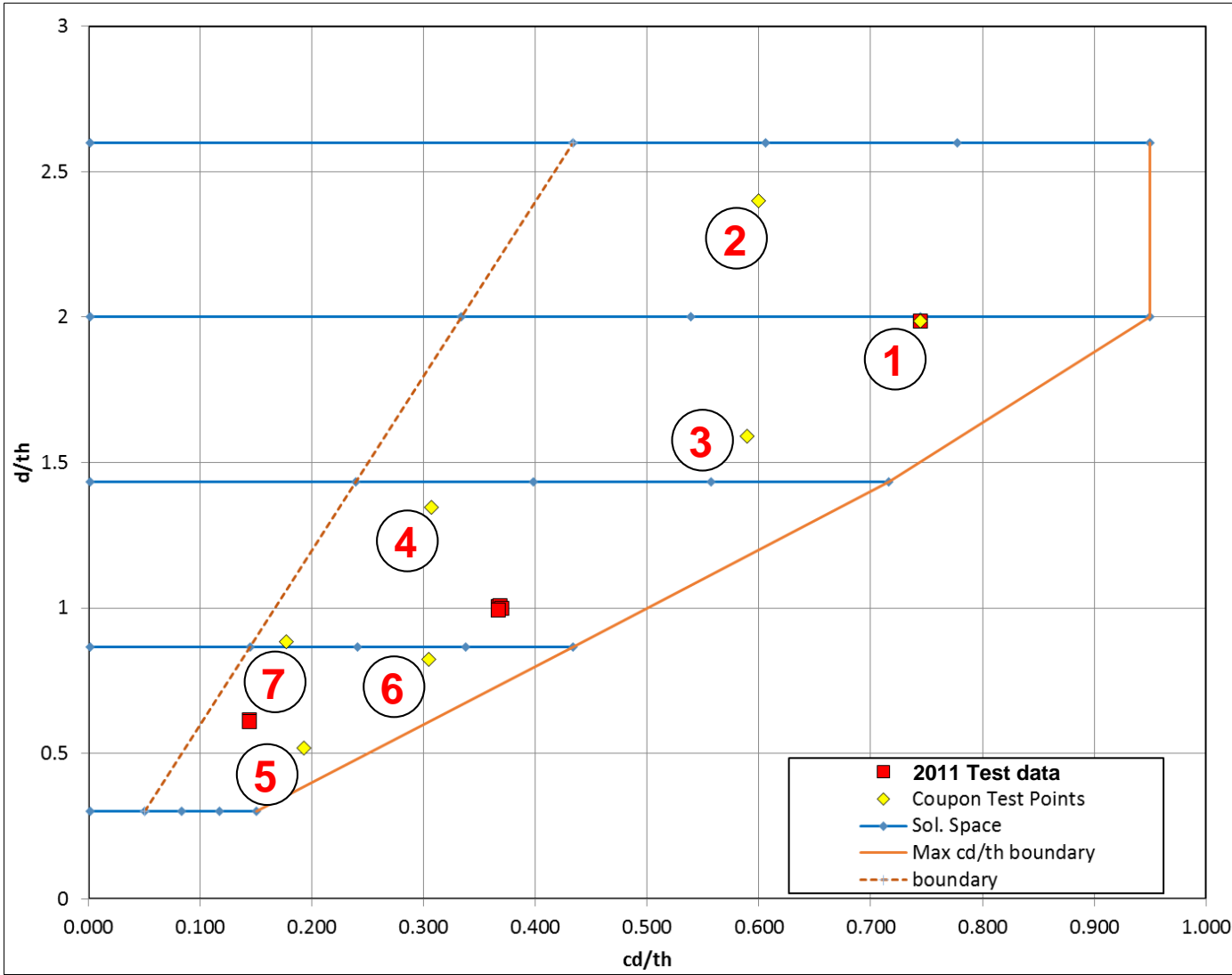


20 | Testing: Solution Space

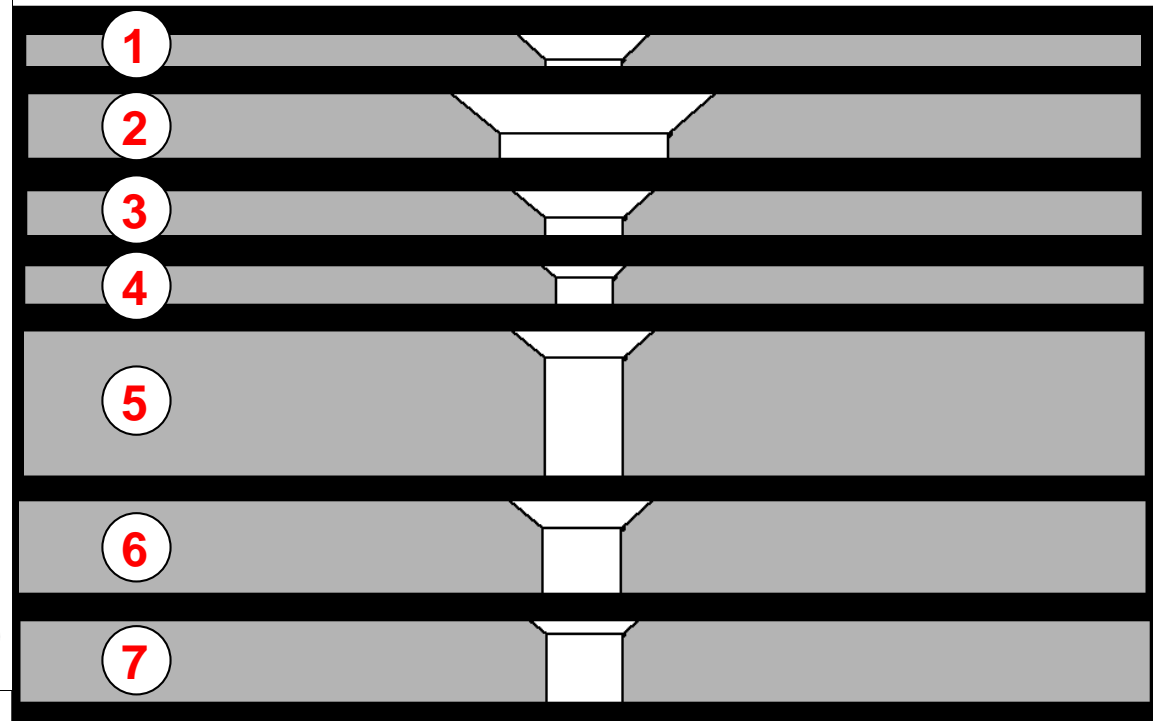
- Geometric data from four weapon systems (*blue & purple points*)
 - hole diameter (d)
 - plate thickness (th)
 - countersink depth (cd)
- Results show a very organized distribution
- FEA solution space details (*yellow points*):
 - Used 25 d/th vs. cd/th points
 - cd/th ranges from 0.001 to 0.95
- Performed validation testing for 3 different geometries (*red points*)



2017 Testing: Solution Space

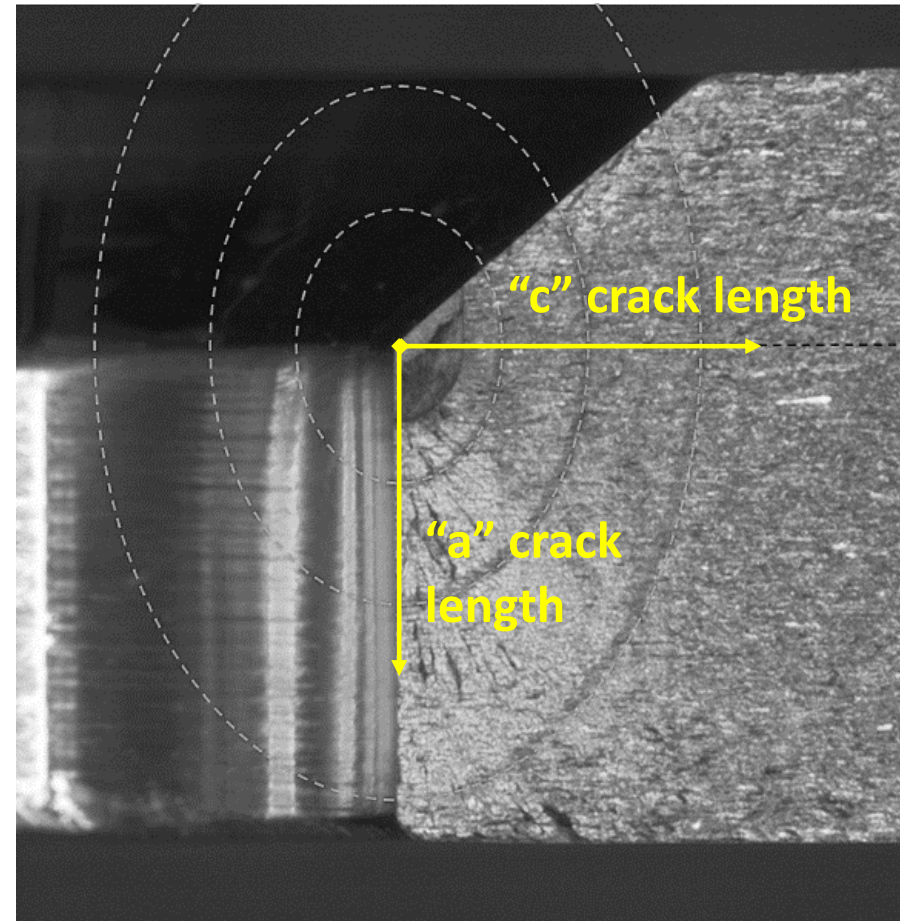


Condition	Plate Thickness	Hole Diameter	Countersink Depth	d/th	cd/th
1	0.137	0.272	0.102	1.98	0.74
2	0.25	0.6	0.15	2.40	0.60
3	0.173	0.275	0.102	1.59	0.59
4	0.15	0.202	0.046	1.34	0.30
5	0.53	0.2755	0.102	0.52	0.19
6	0.335	0.2755	0.102	0.82	0.30
7	0.300	0.266	0.053	0.88	0.17



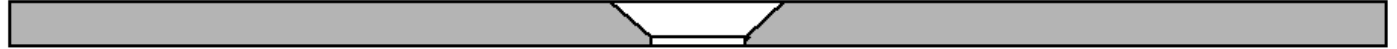
2017 Testing: Details

- Calculation of ΔK from test data
 - Calculate $\Delta a/\Delta N$ from set of measurements = da/dN
 - Go to material crack growth rate data
 - Interpolate da/dN to get resulting ΔK_{test}
 - Repeat for each set of measurements
- 2 AFGROW analyses run for each condition
 - Case 1: Initial ‘a’ and ‘c’ lengths averaged then $a/c \text{ avg} = 1 = \text{constant}$
 - Case 2: Initial ‘a’ and ‘c’ lengths
- Plots of crack length vs. cycles and ΔK vs. crack length for each condition

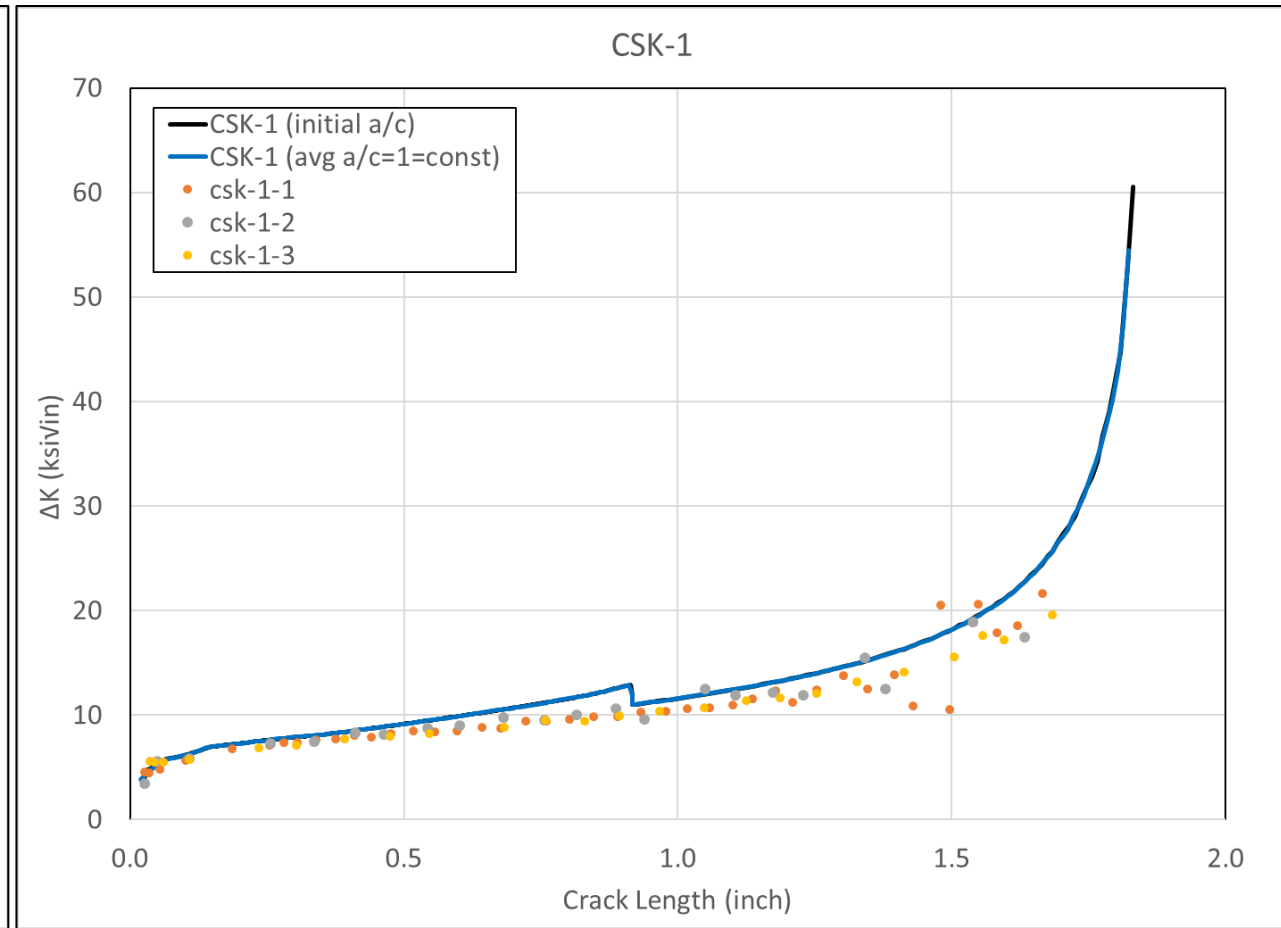
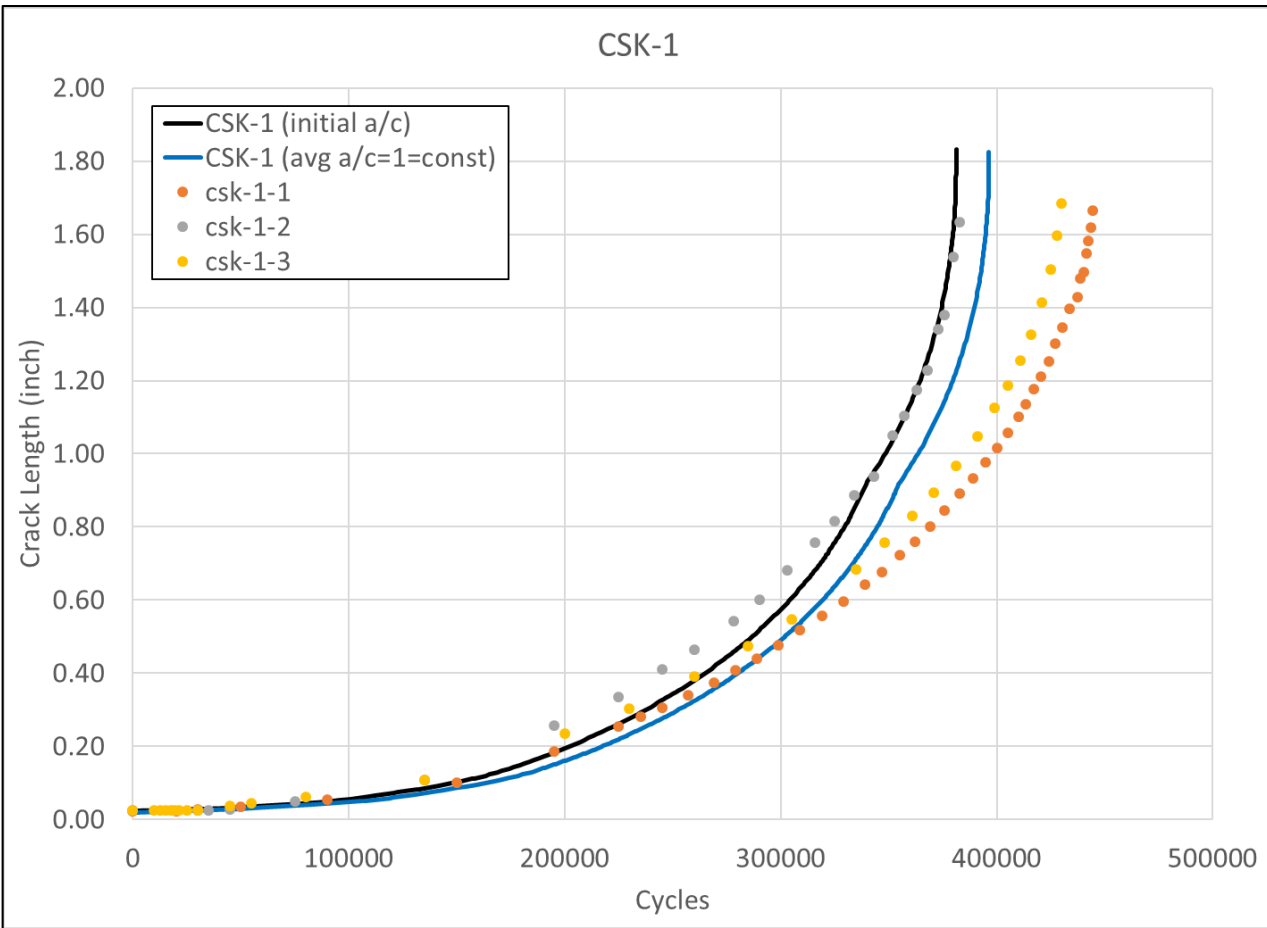


Aluminum or Metal	
da/dN	ΔK R=0.1
3.16E-08	2.746
4.89E-08	2.828
7.57E-08	2.912
1.17E-07	3.155
1.81E-07	3.669
2.80E-07	4.183
4.33E-07	4.620
6.70E-07	5.456
1.04E-06	5.860
1.60E-06	6.487
2.48E-06	7.326
3.84E-06	8.368
5.94E-06	9.646
9.19E-06	11.209
1.42E-05	13.098
2.20E-05	15.350
3.40E-05	17.903
5.26E-05	20.661
8.14E-05	23.438
1.26E-04	26.066

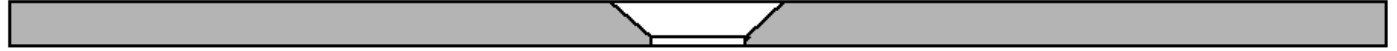
Sample CSK-I



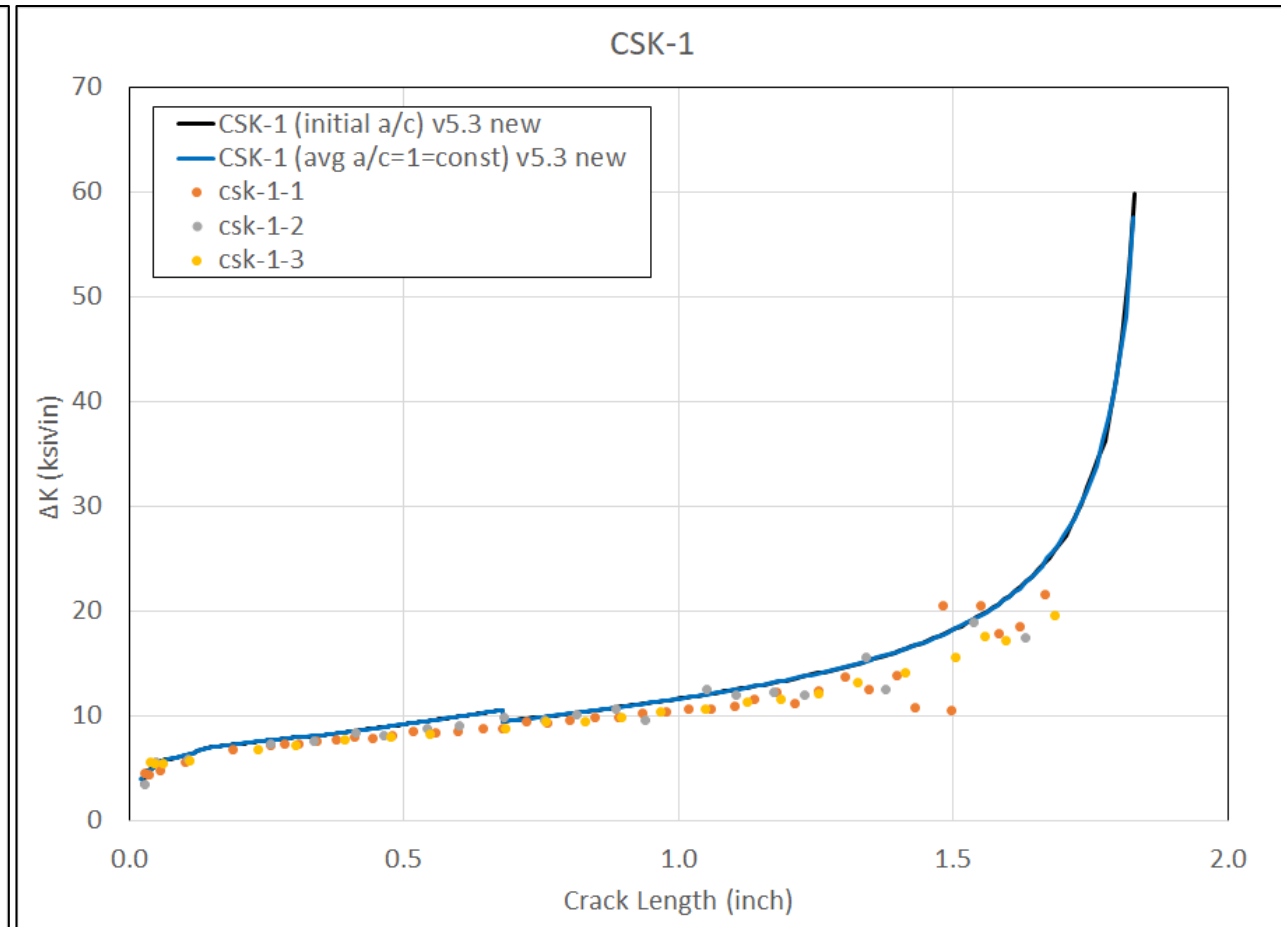
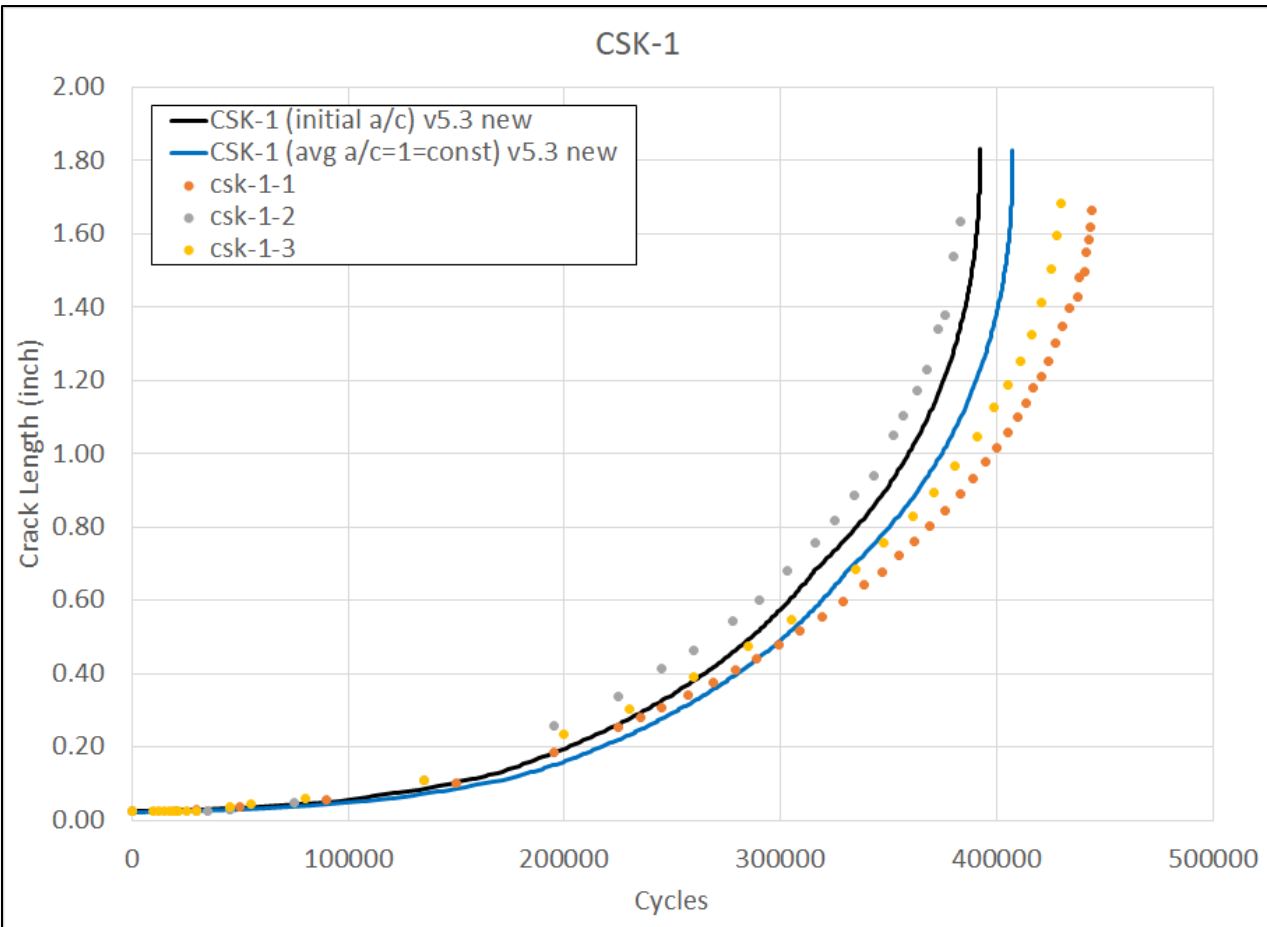
Original AFGROW v5.3



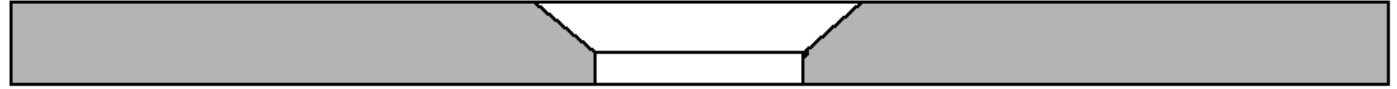
Sample CSK-I



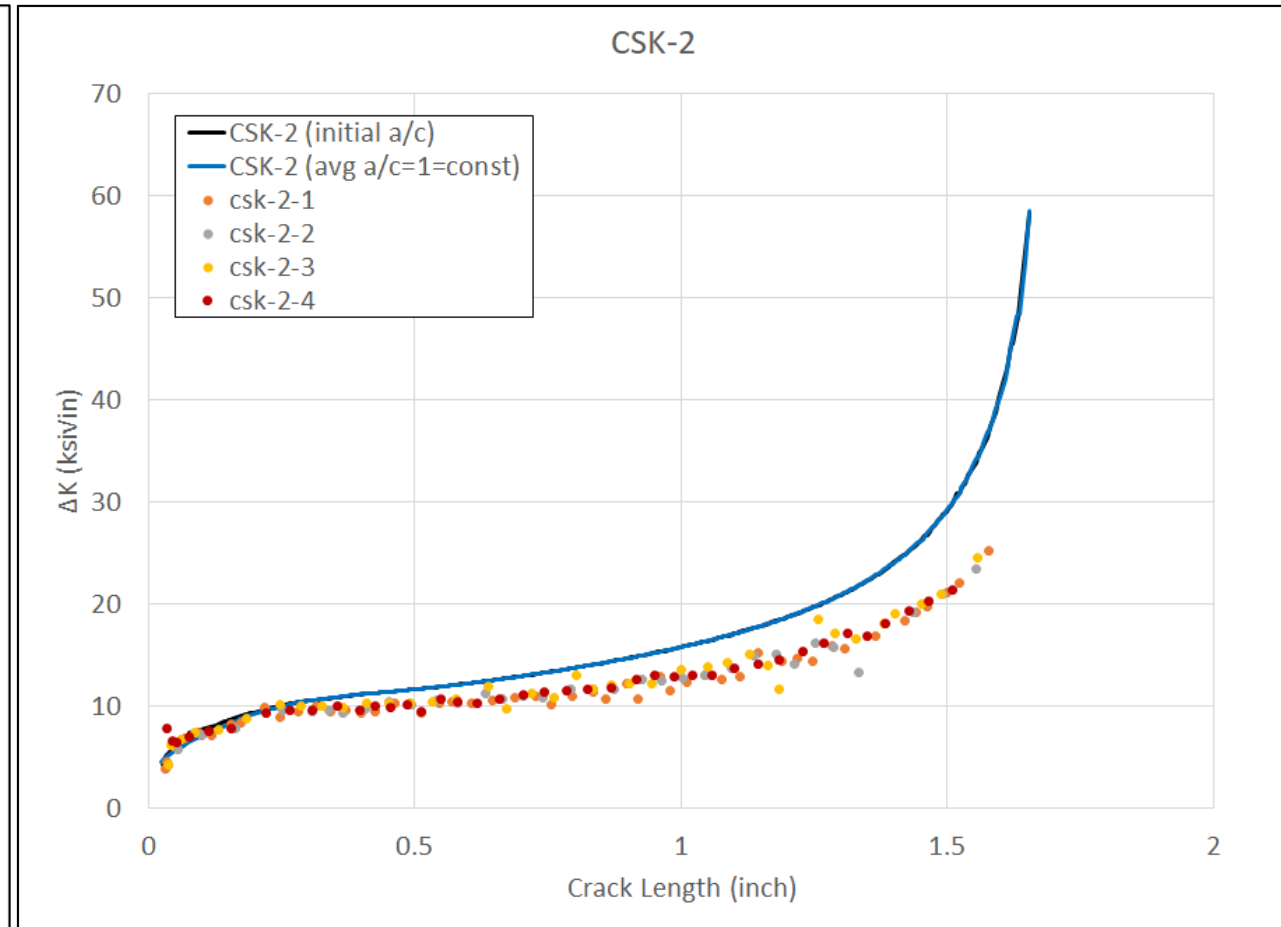
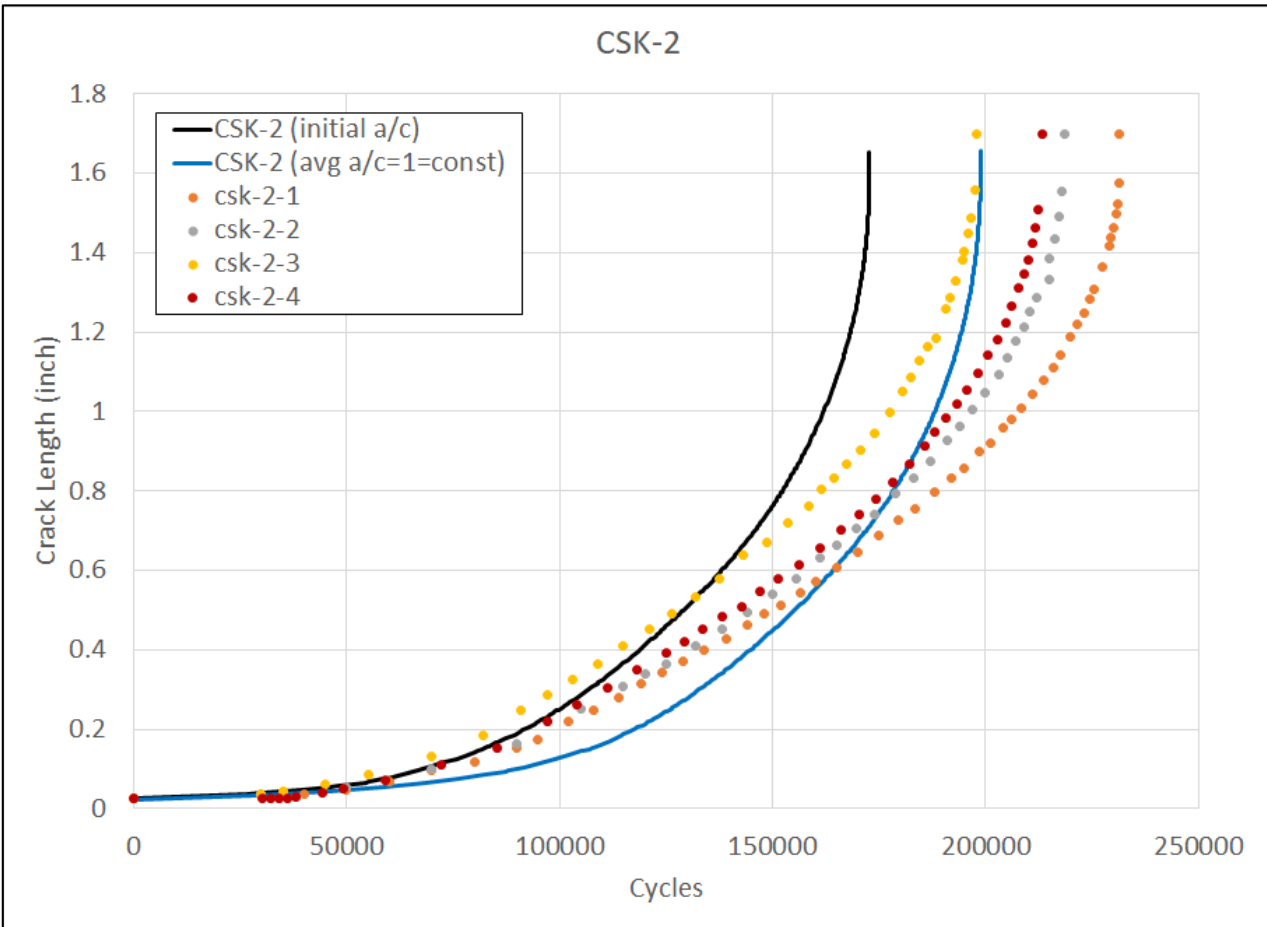
- Updated AFGROW v5.3



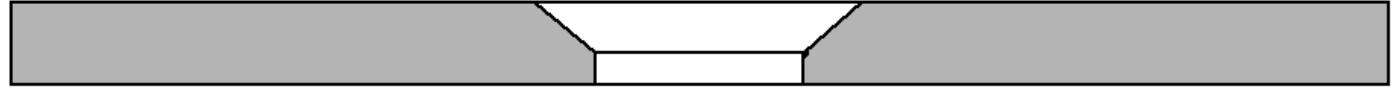
Sample CSK-2



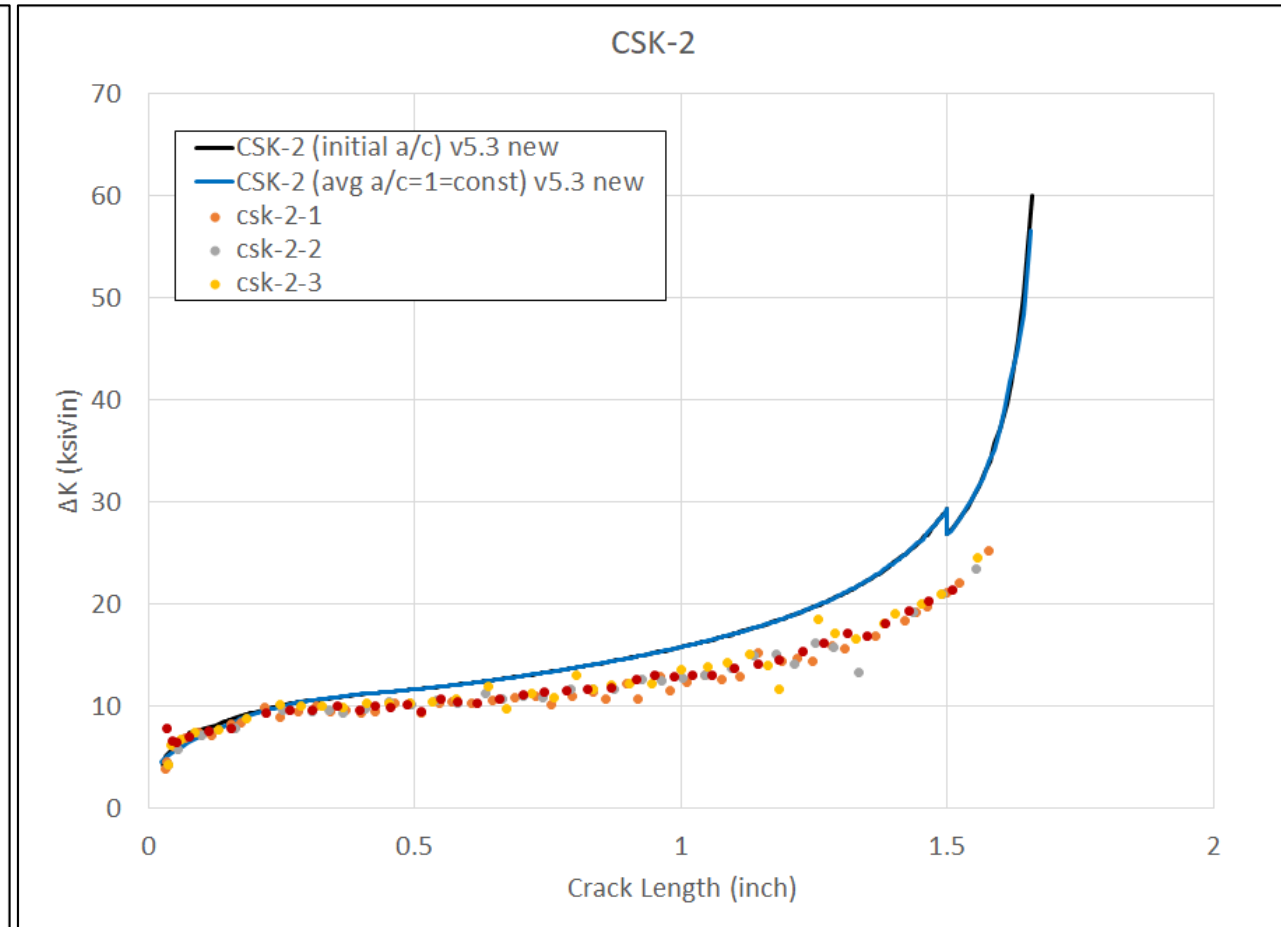
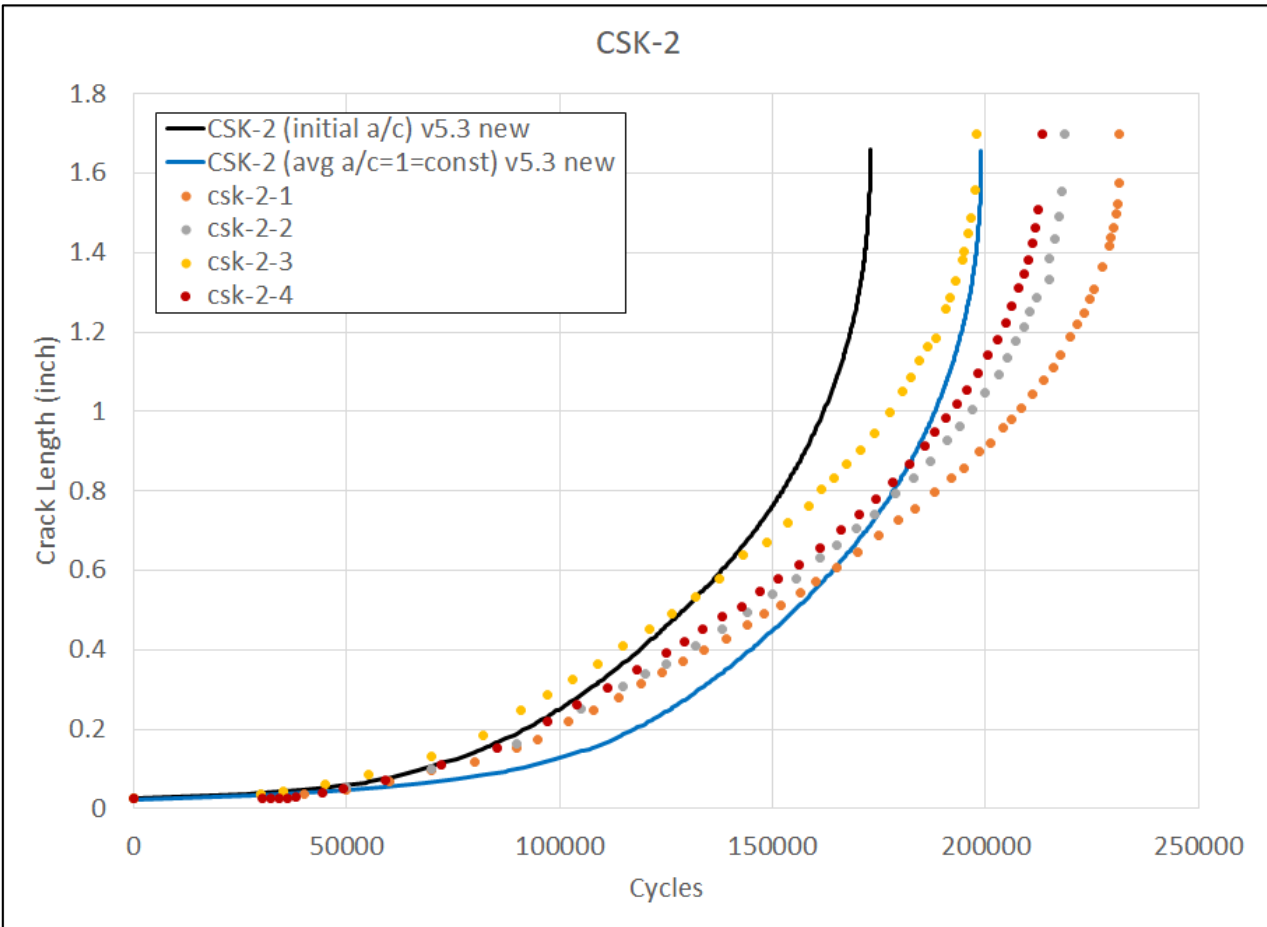
Original AFGROW v5.3



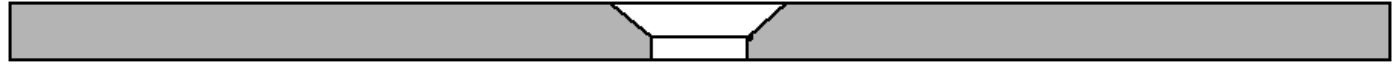
Sample CSK-2



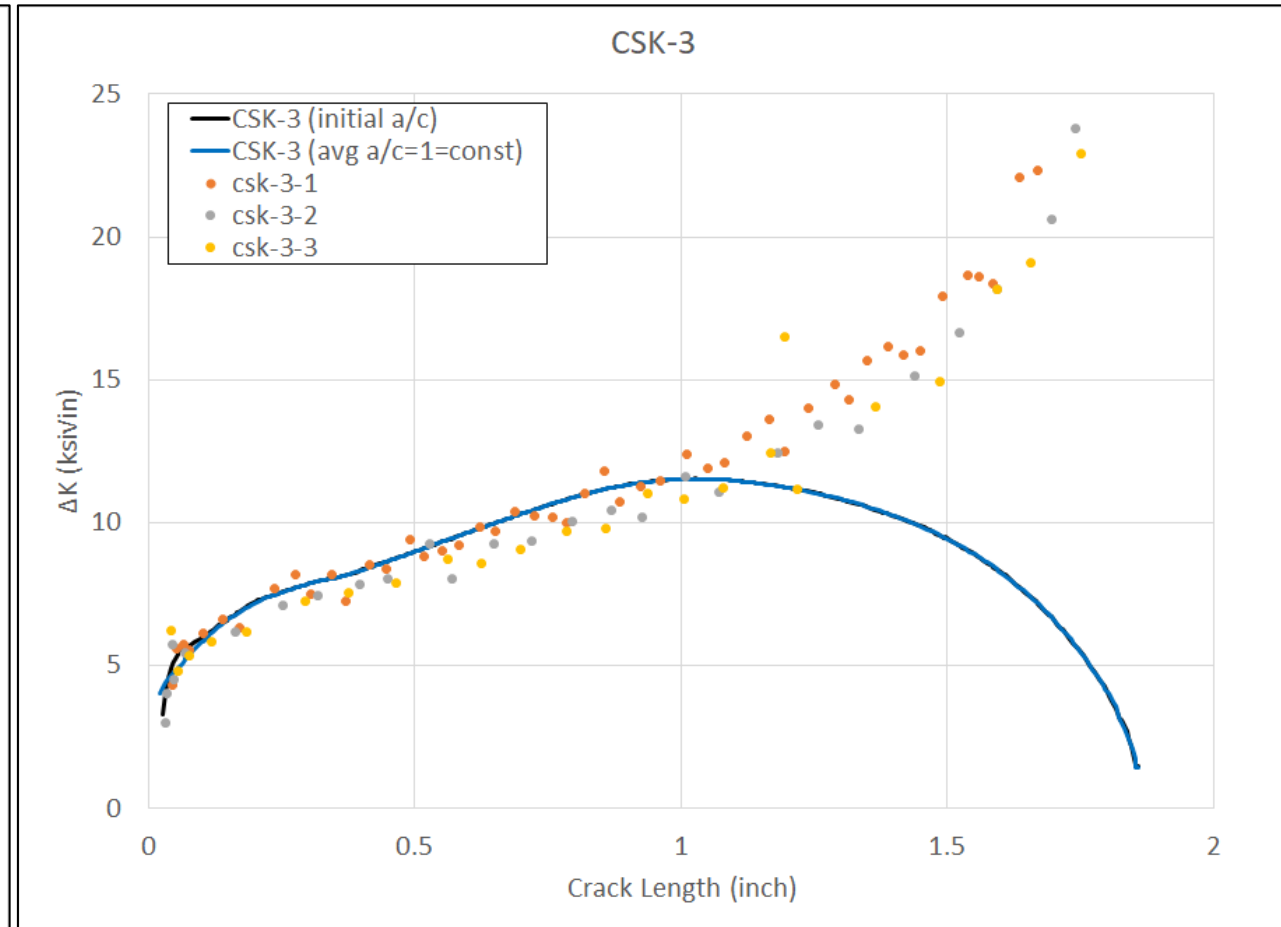
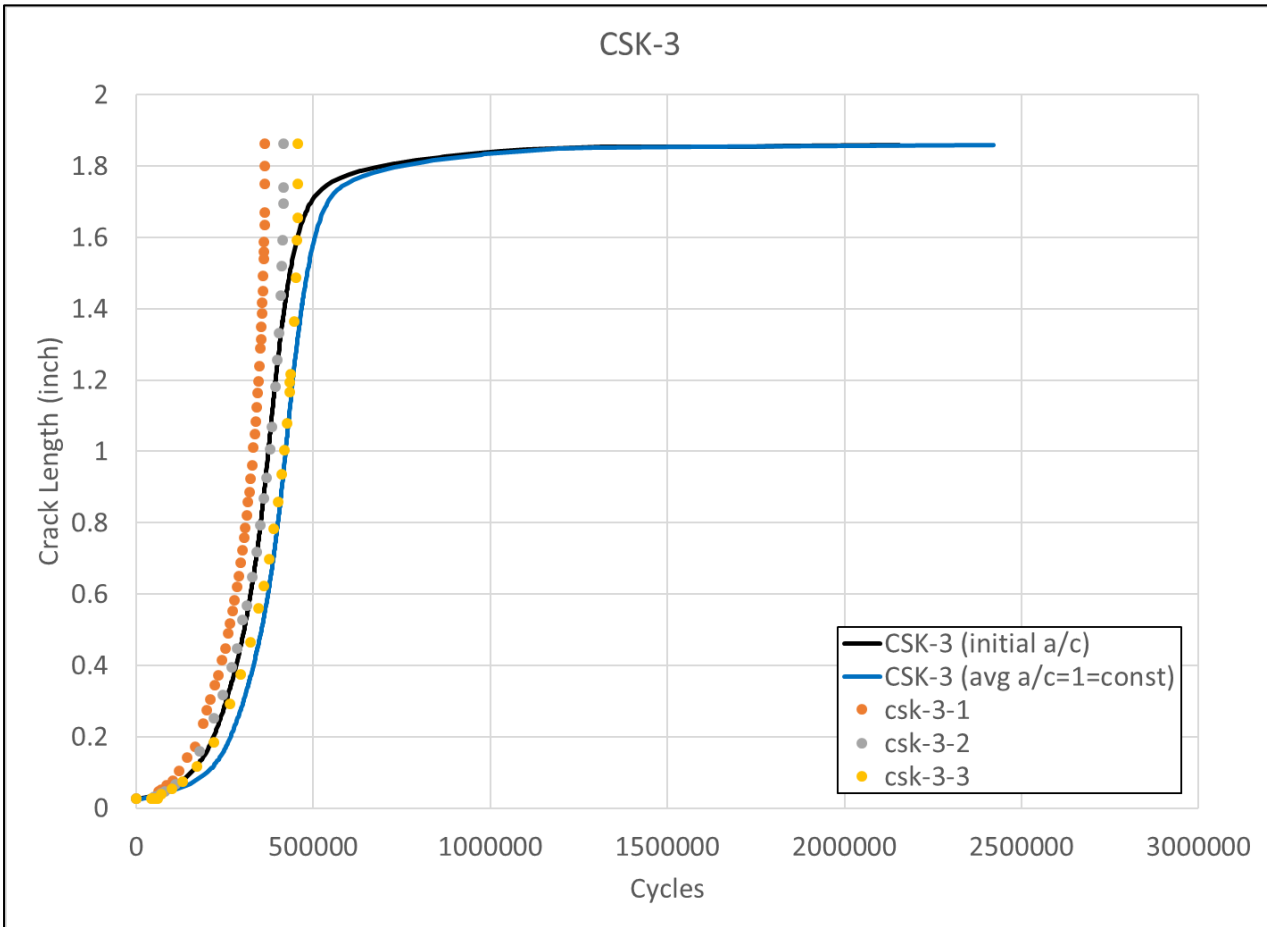
- Updated AFGROW v5.3



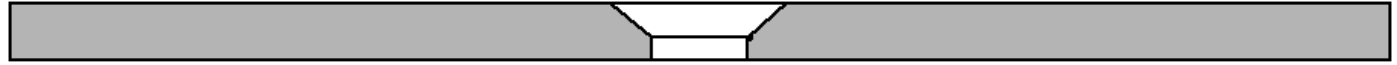
Sample CSK-3



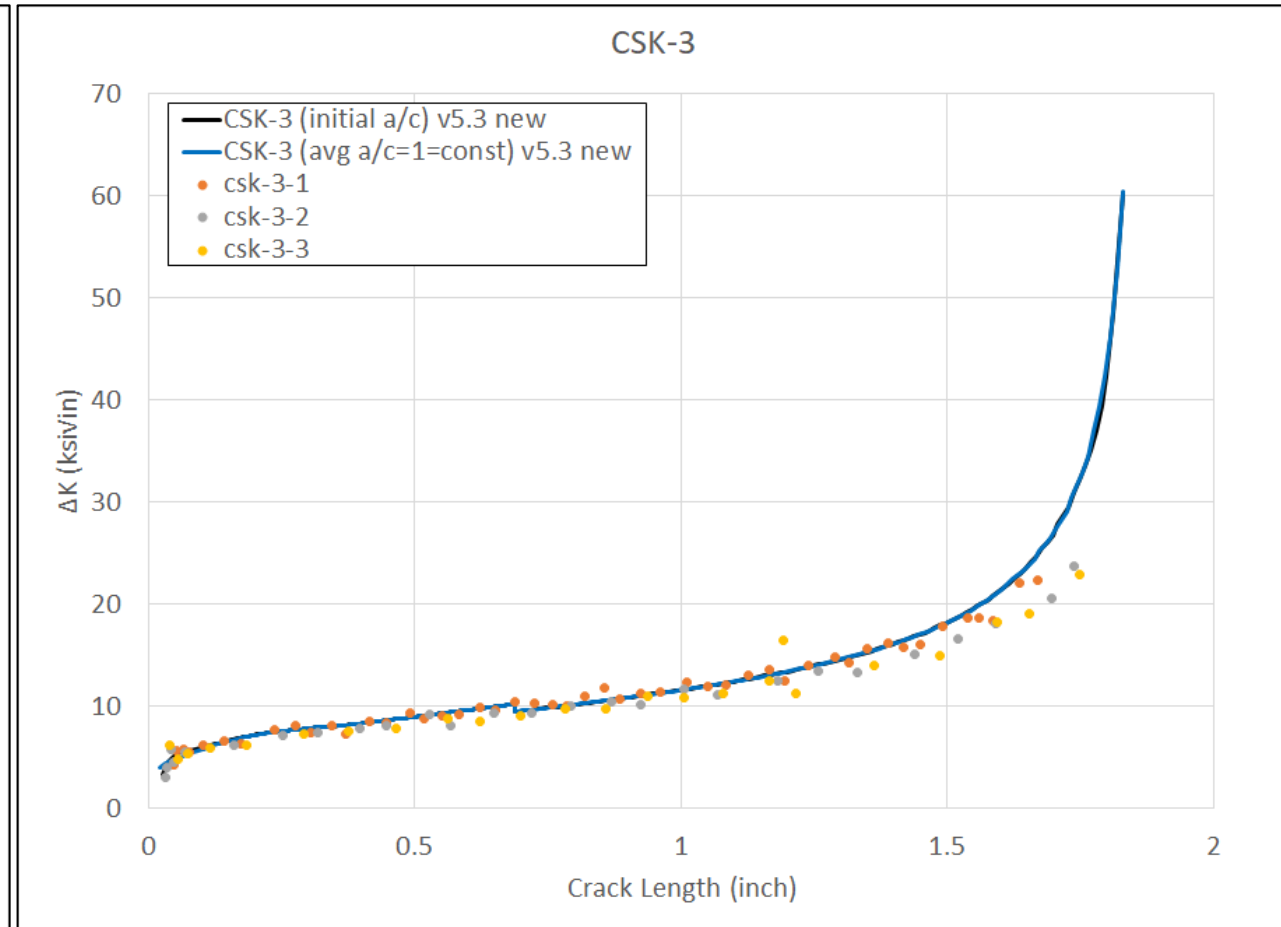
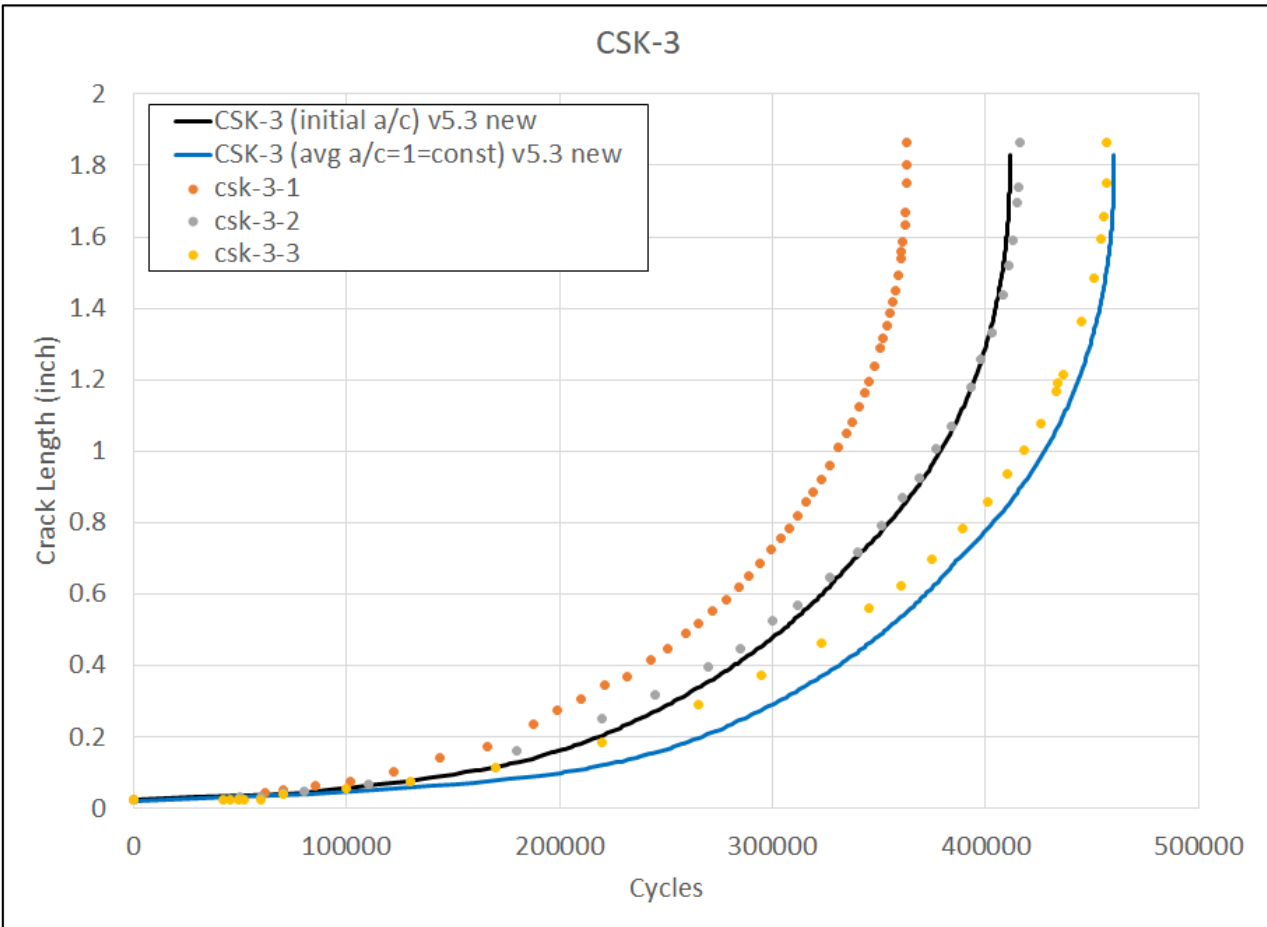
Original AFGROW v5.3



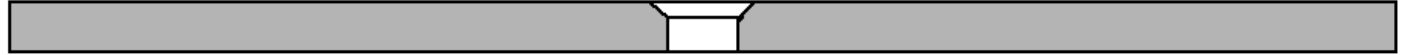
Sample CSK-3



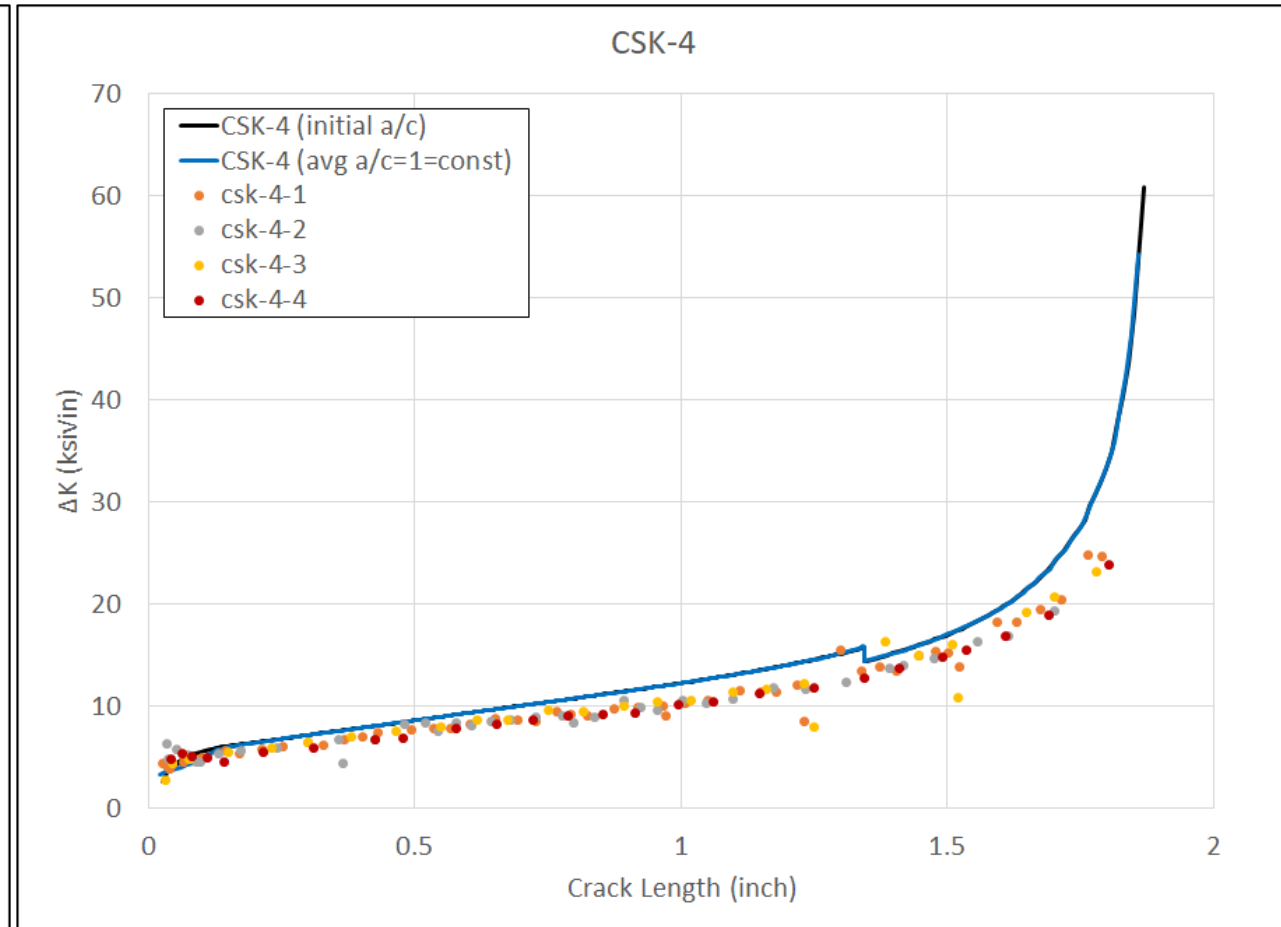
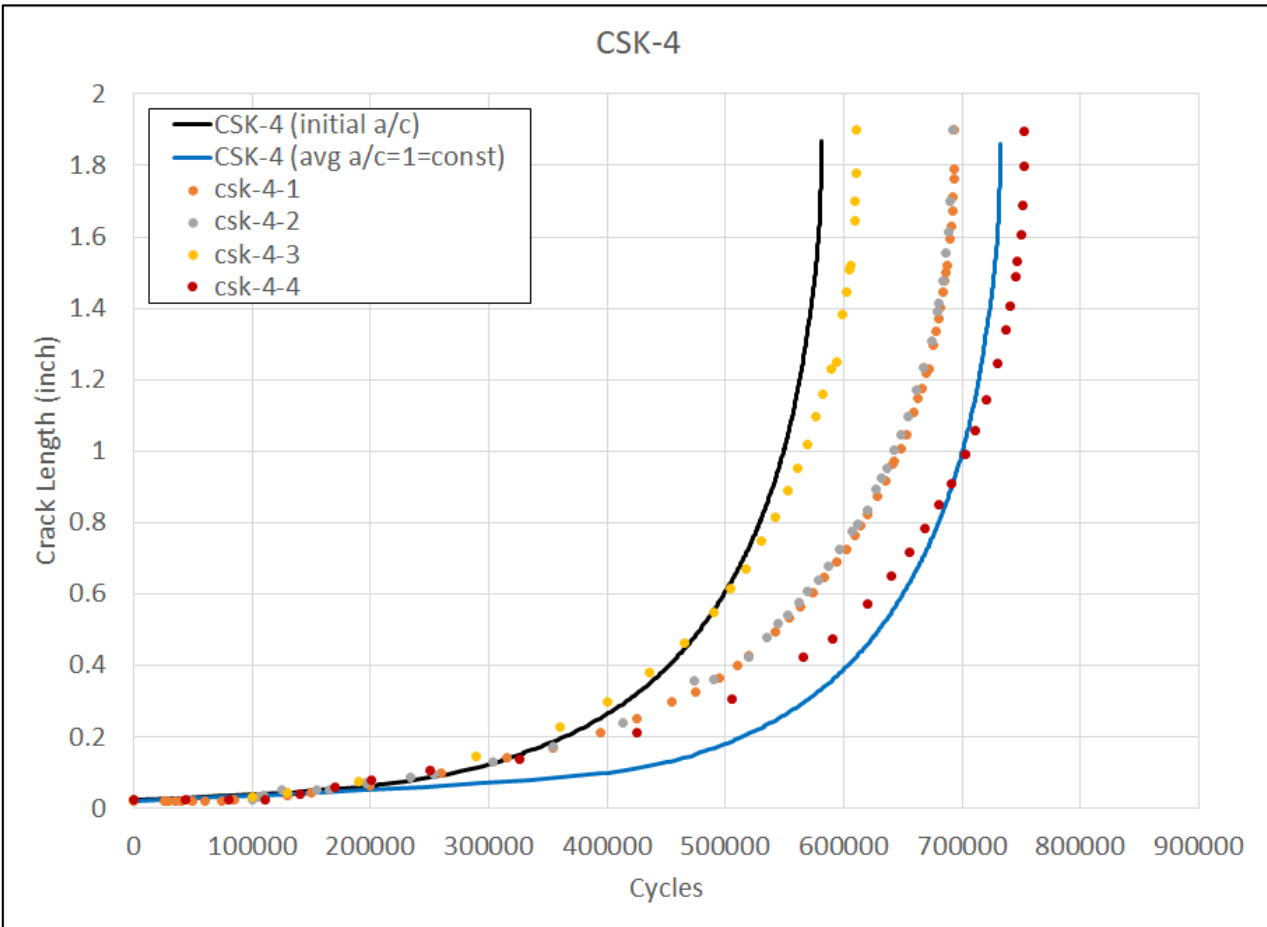
Updated AFGROW v5.3



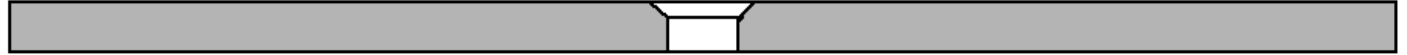
Sample CSK-4



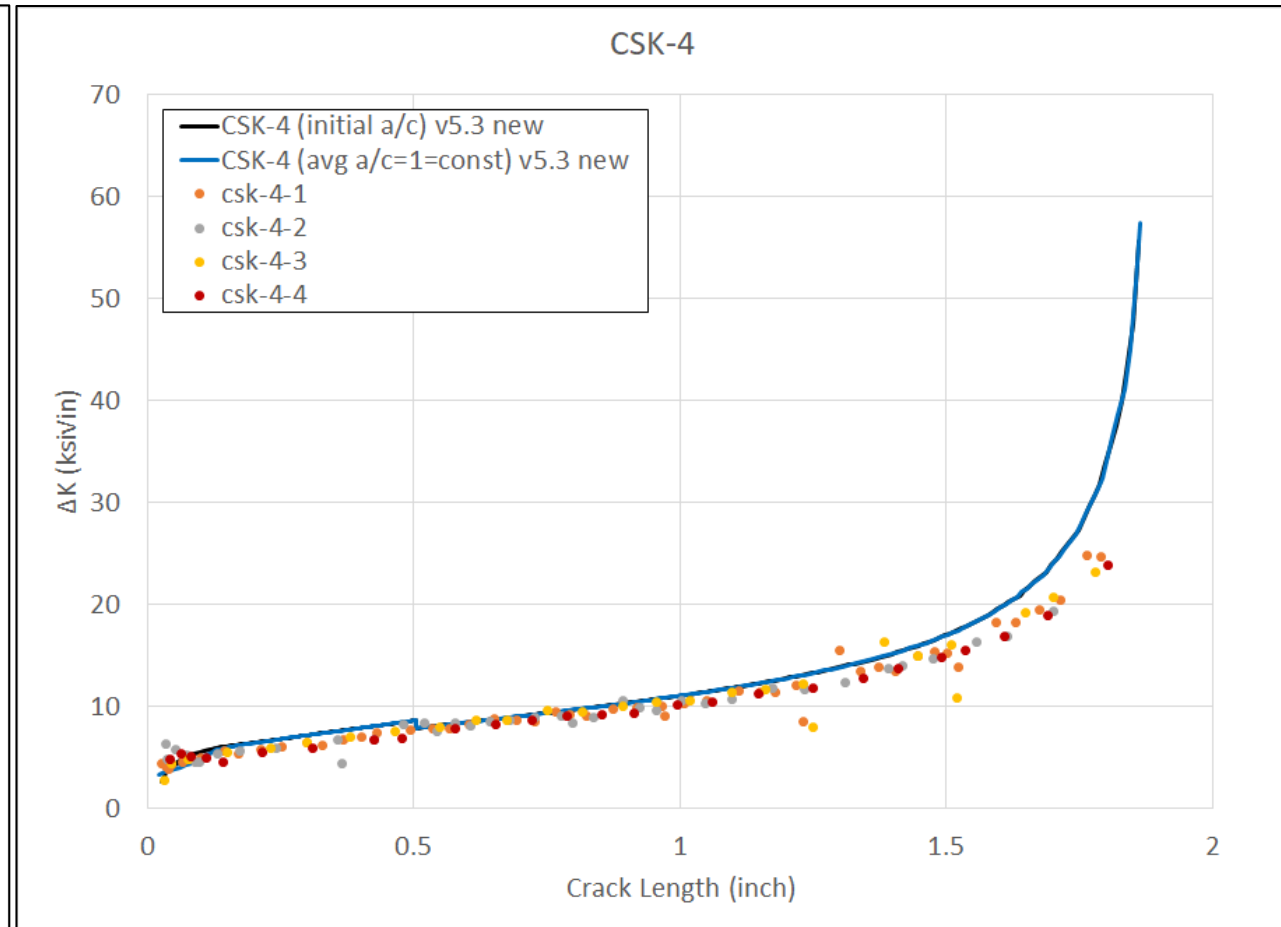
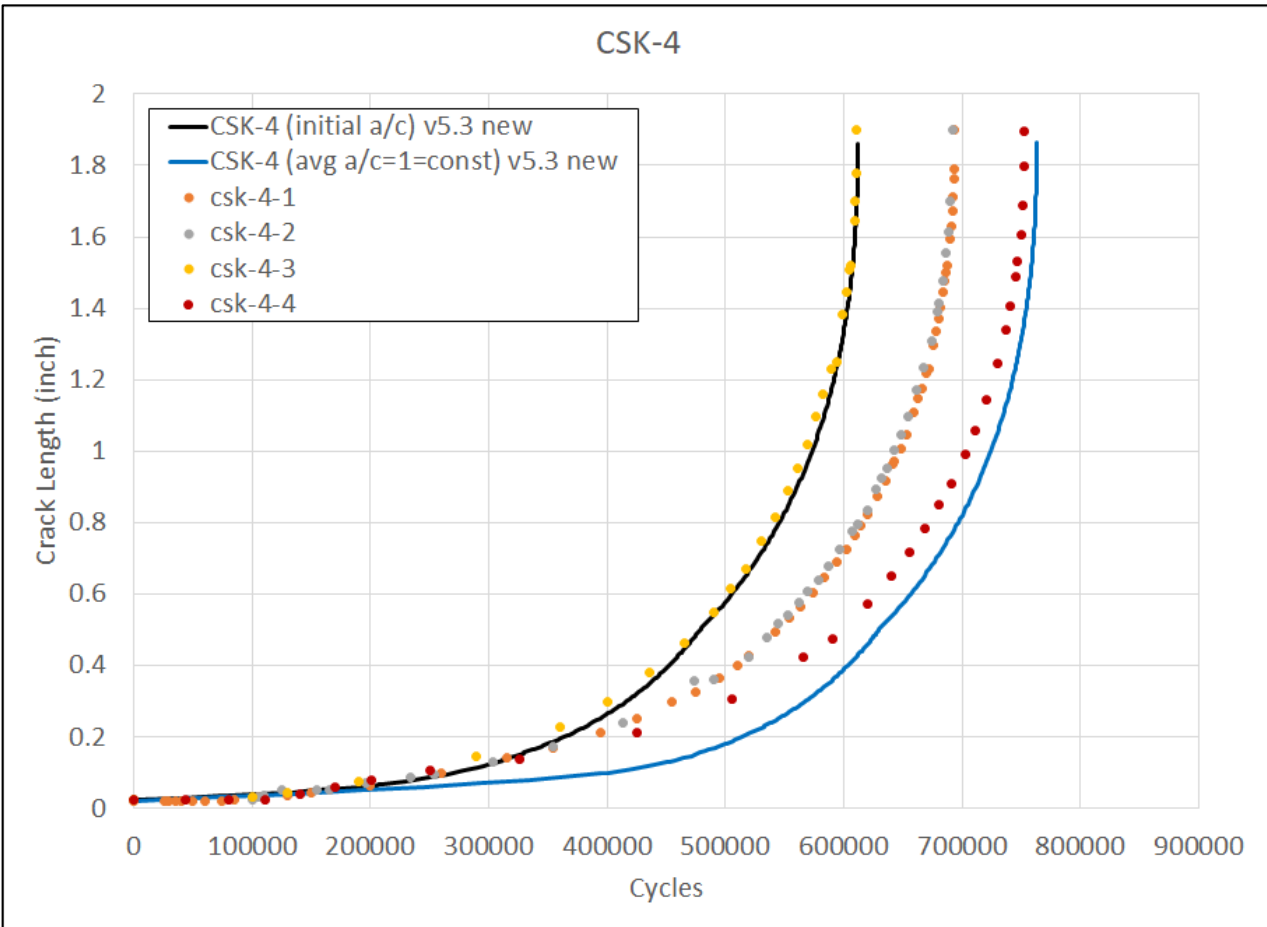
Original AFGROW v5.3



Sample CSK-4

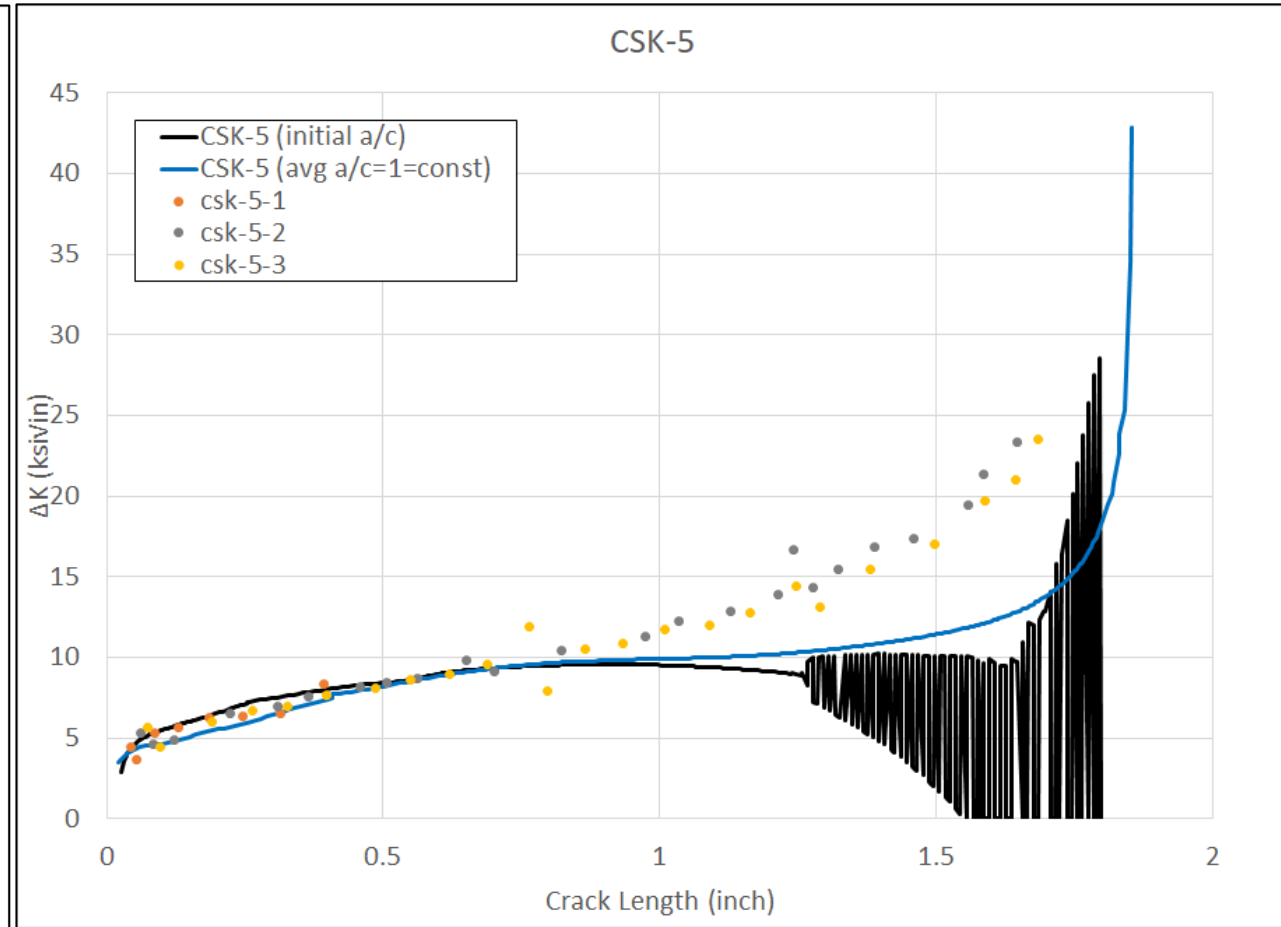
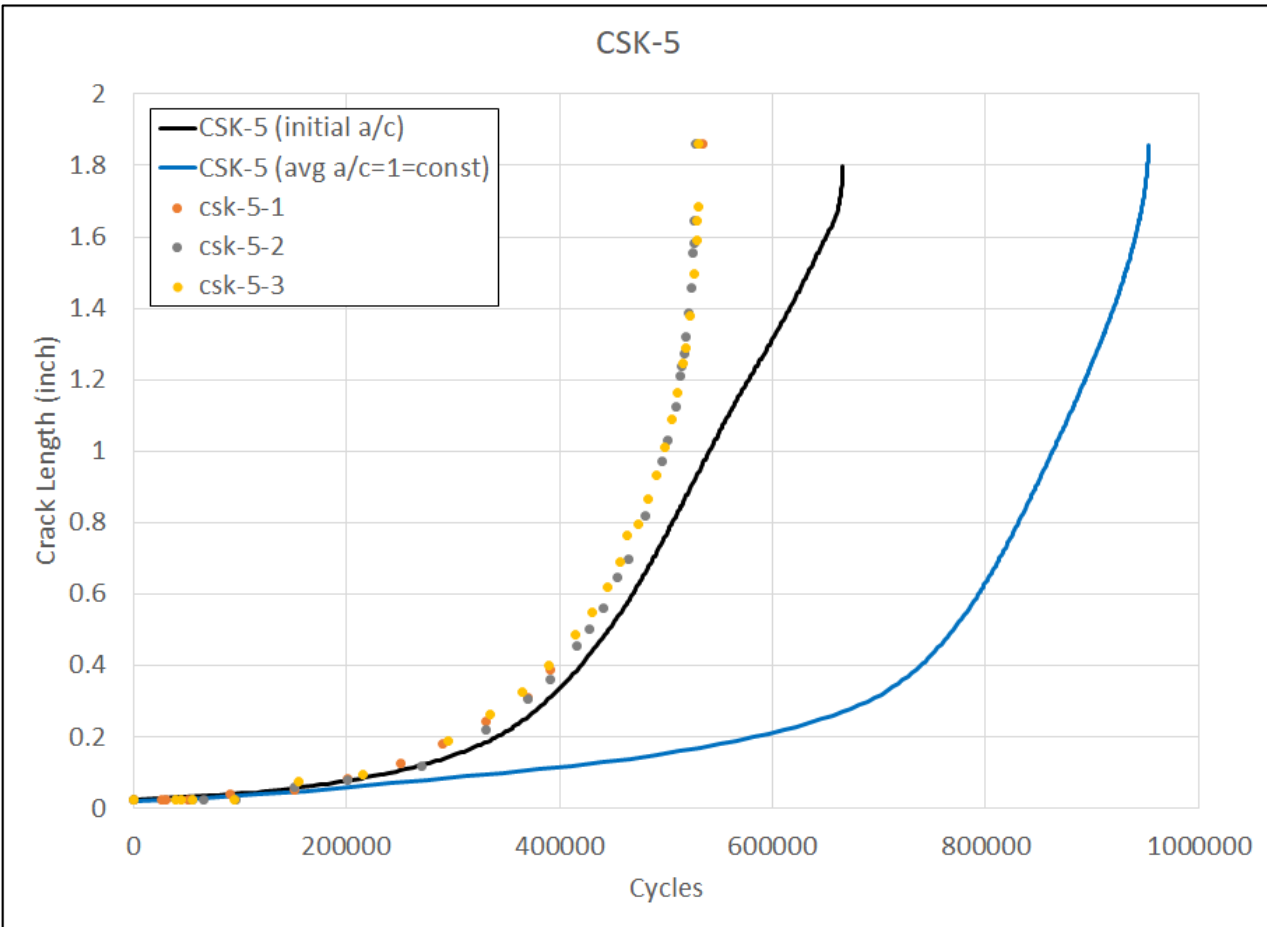
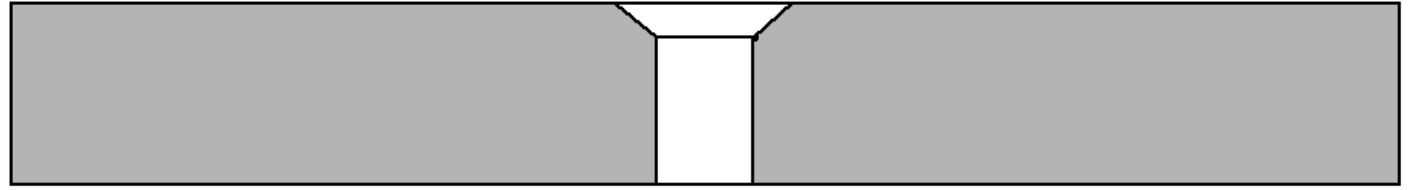


Updated AFGROW v5.3



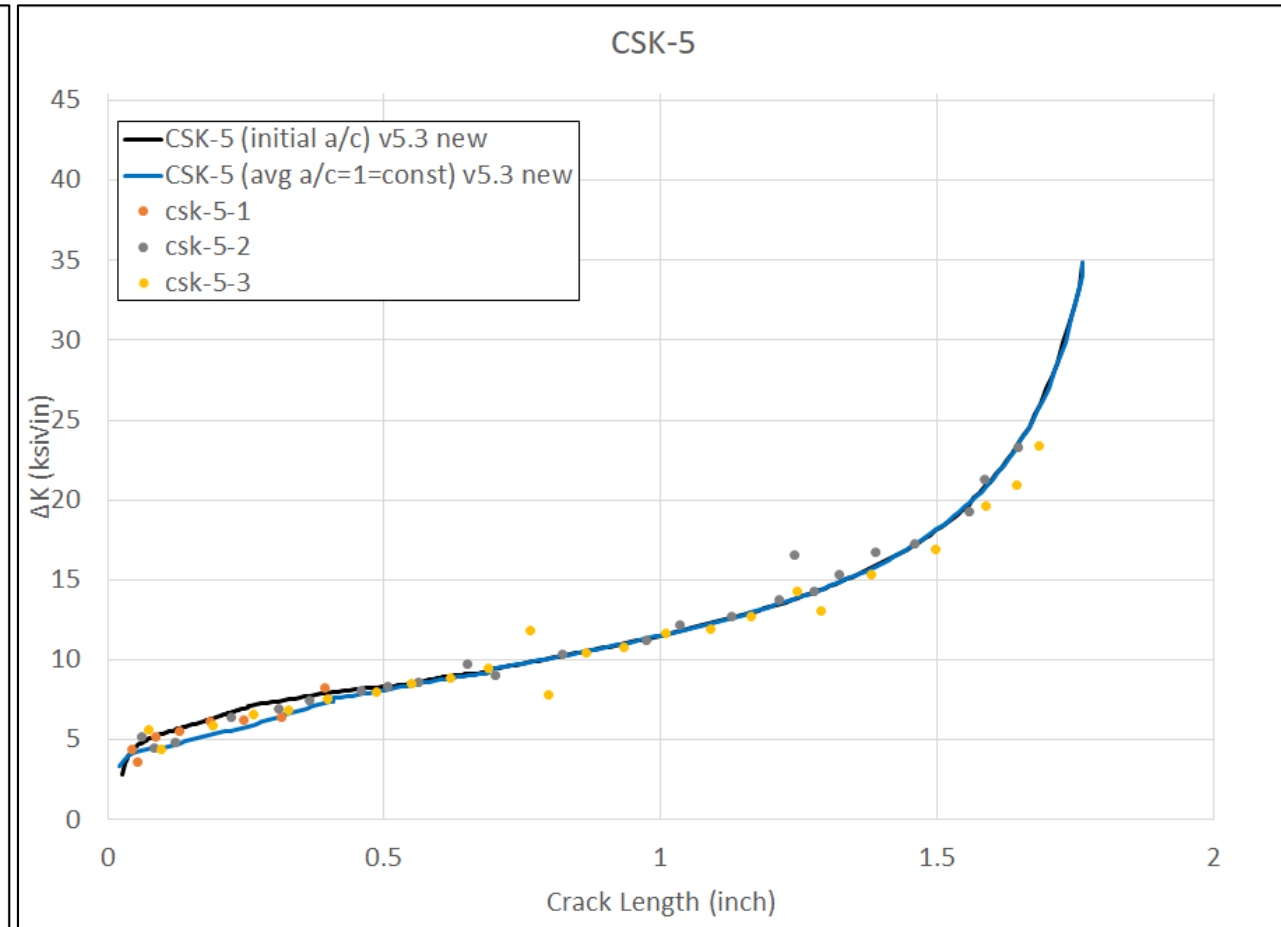
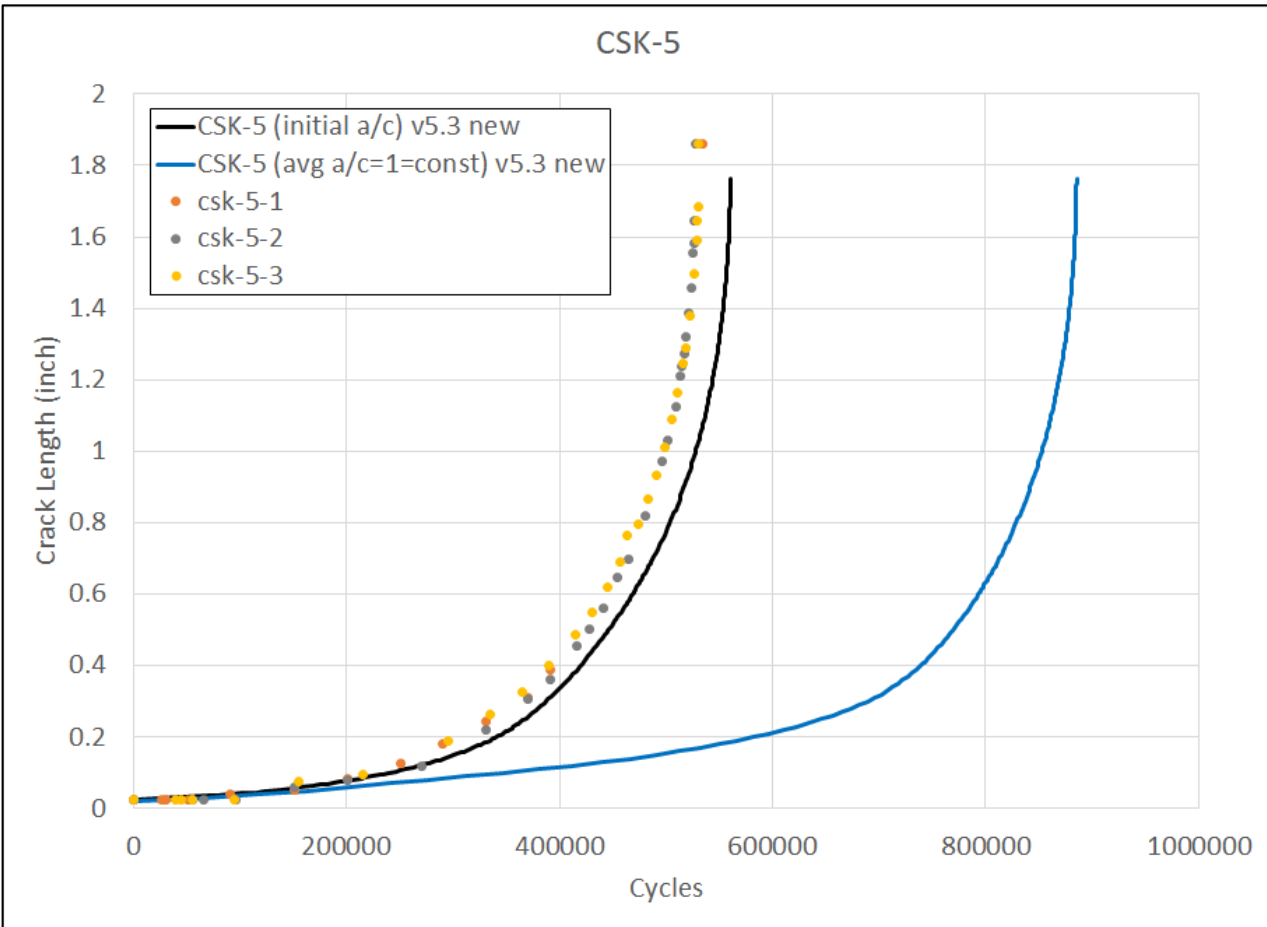
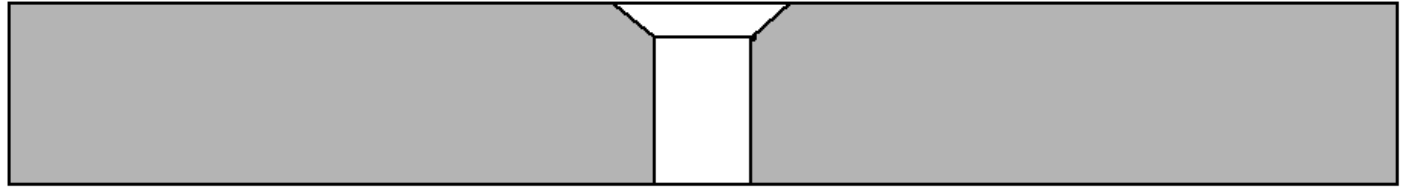
Sample CSK-5

Original AFGROW v5.3

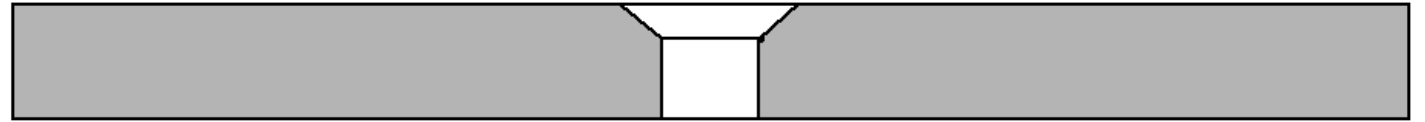


Sample CSK-5

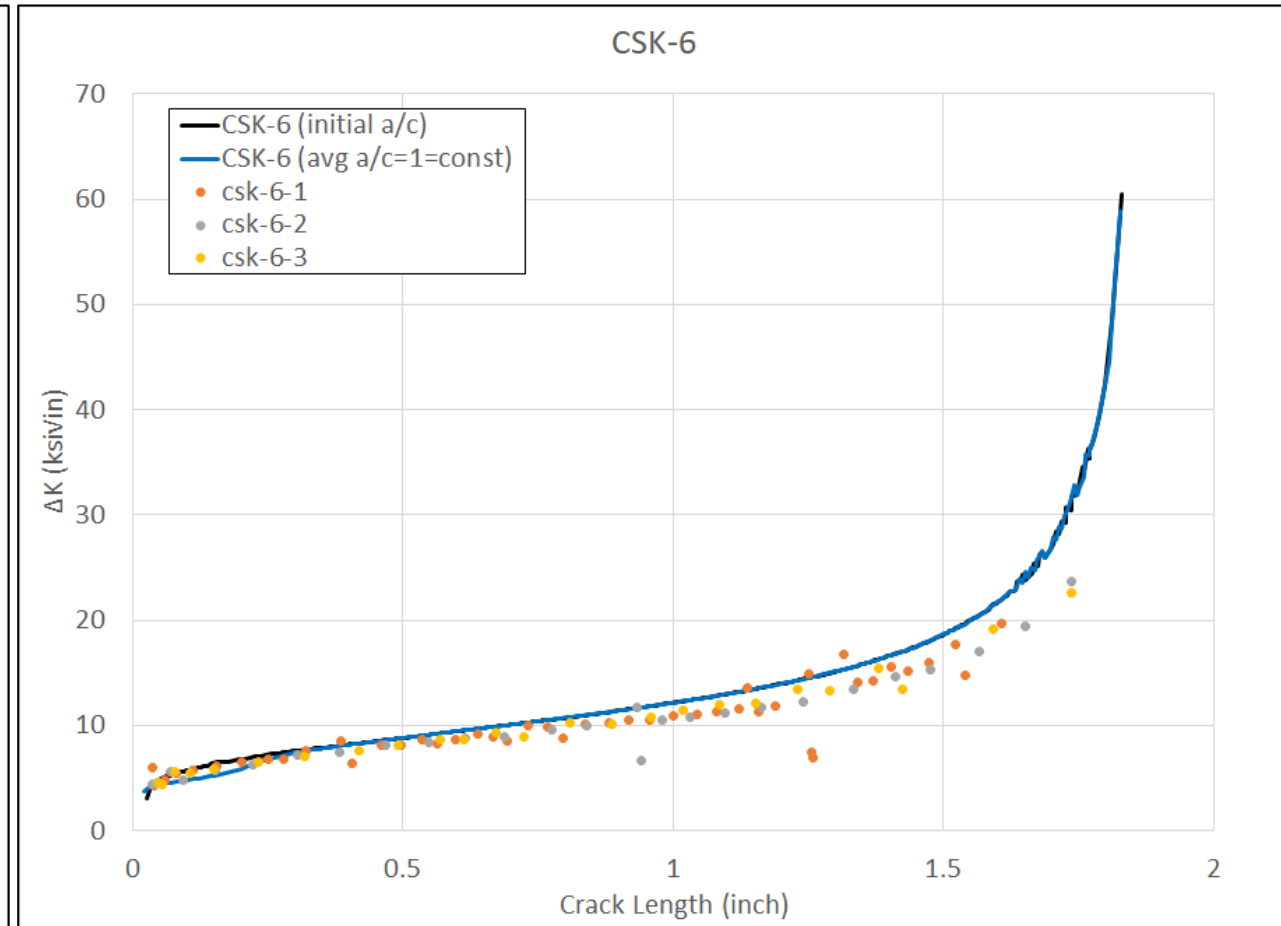
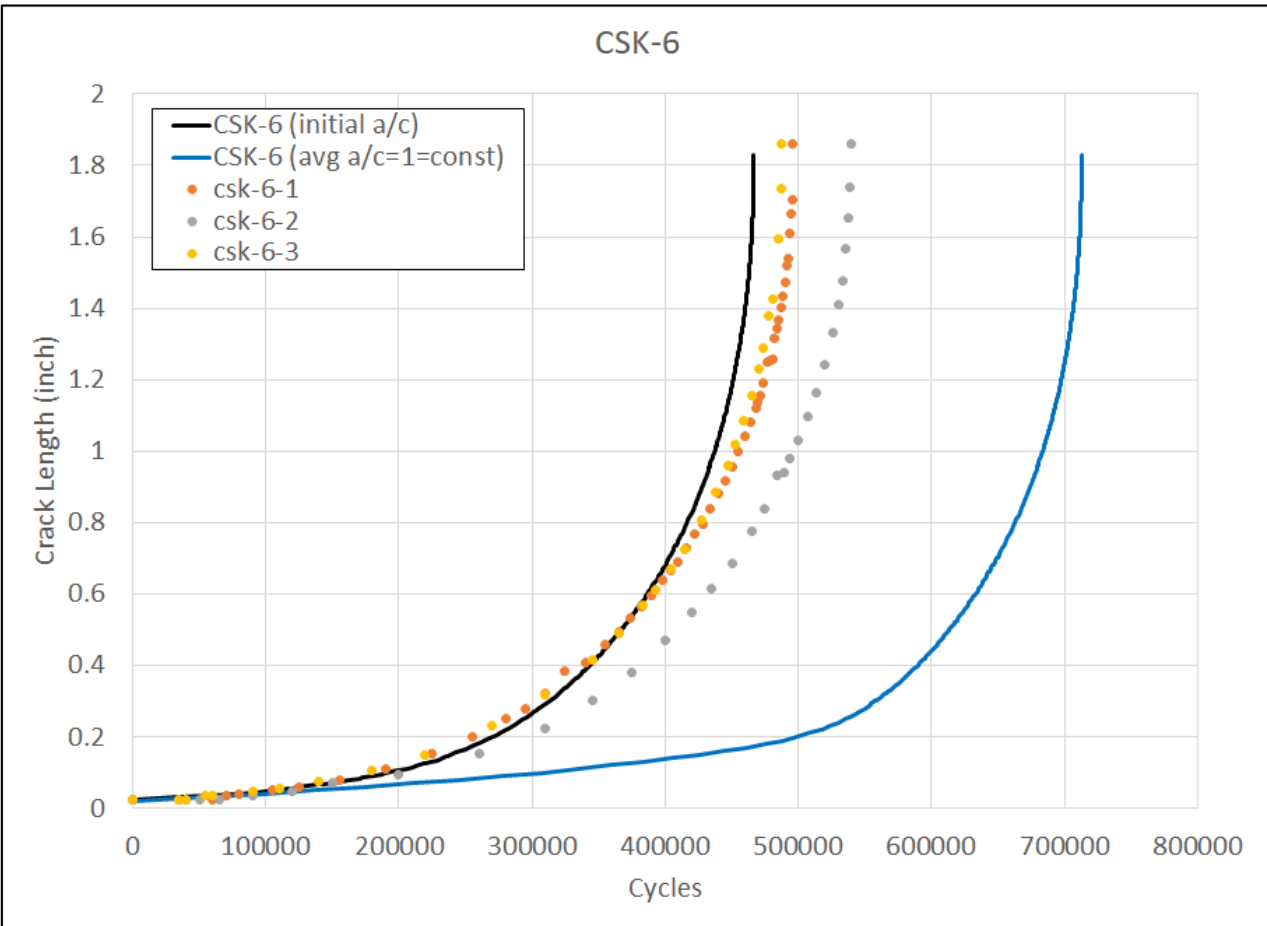
- Updated AFGROW v5.3



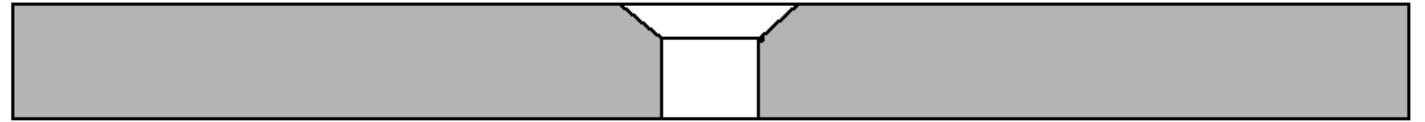
Sample CSK-6



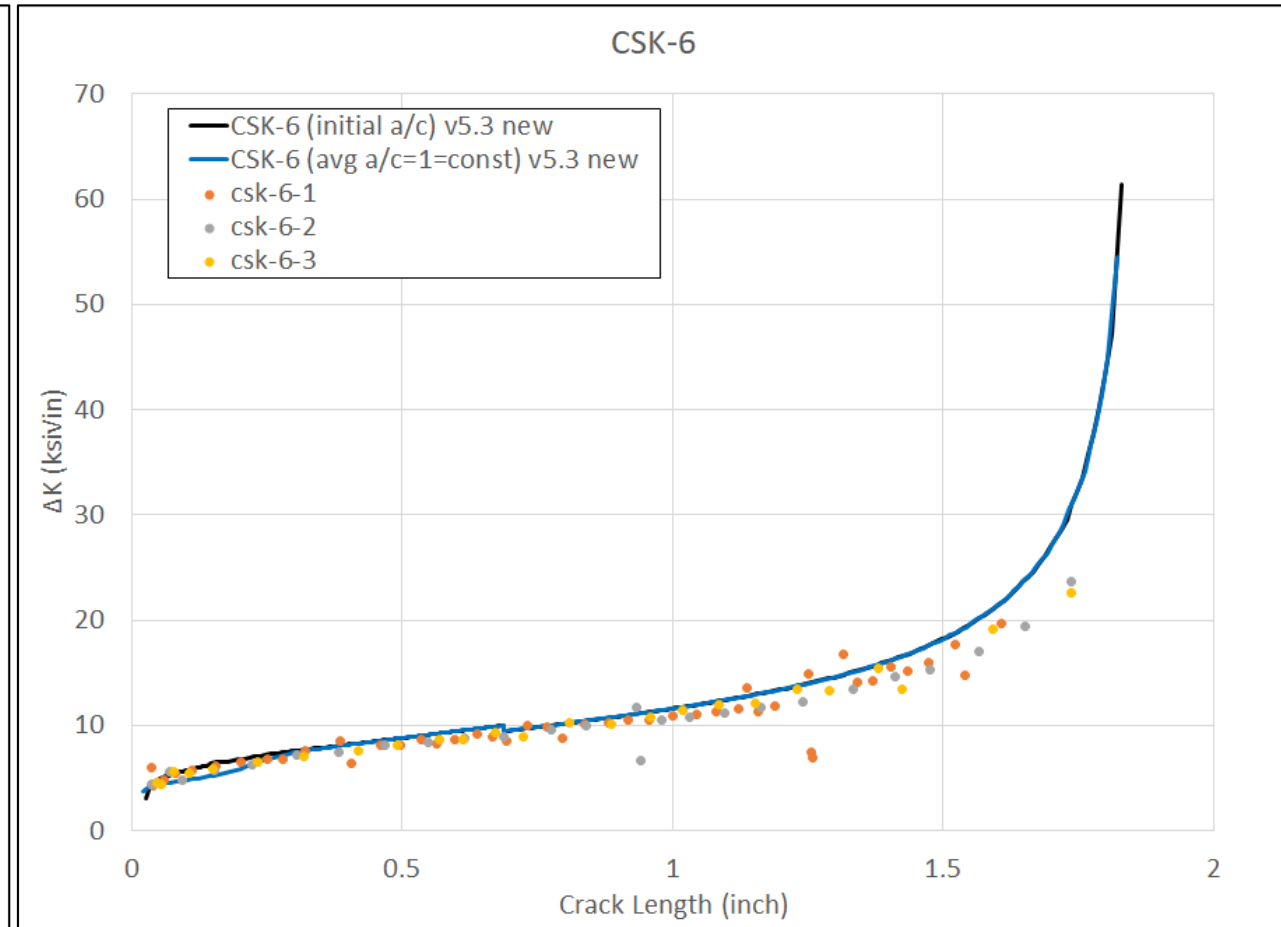
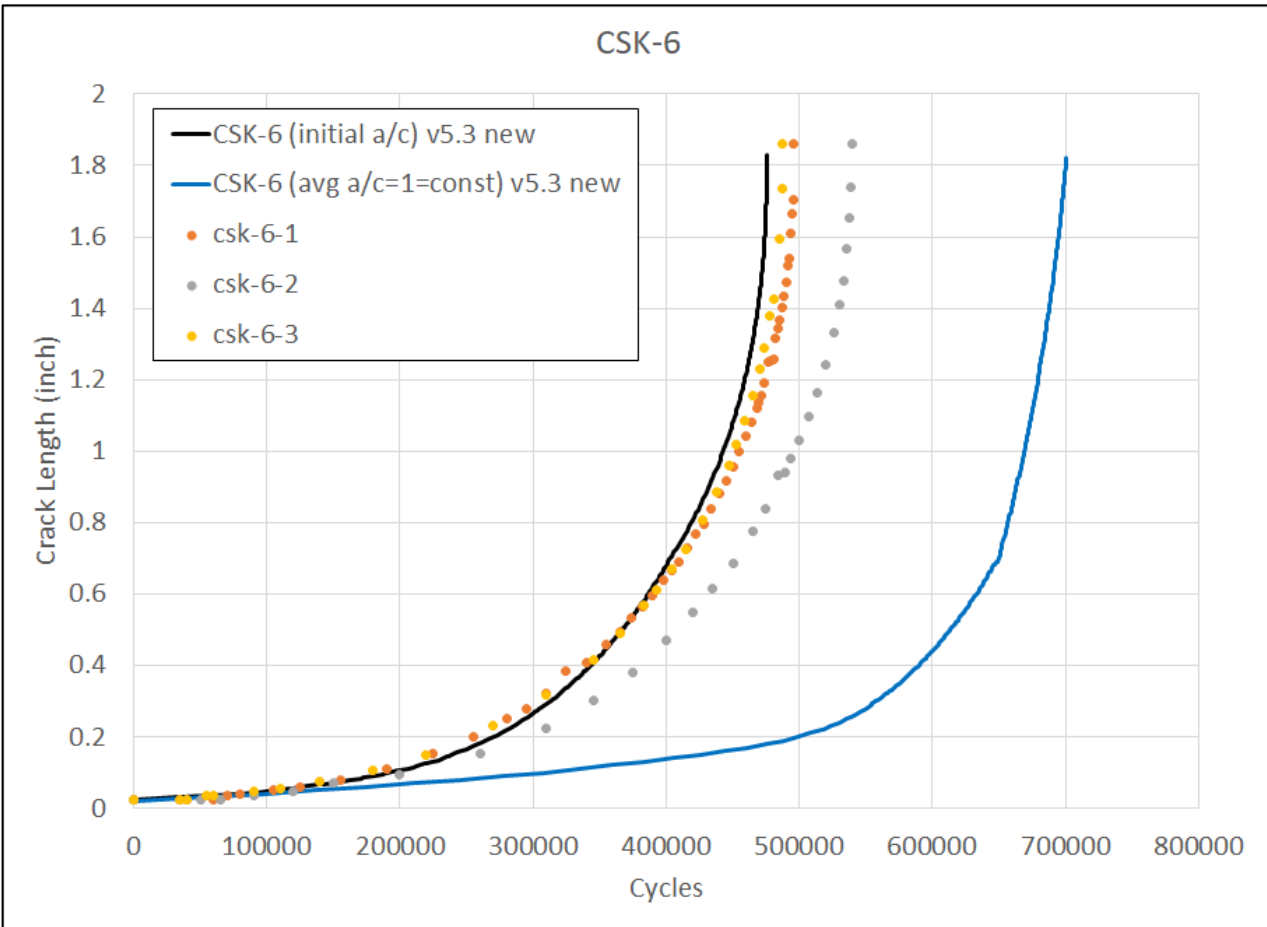
Original AFGROW v5.3



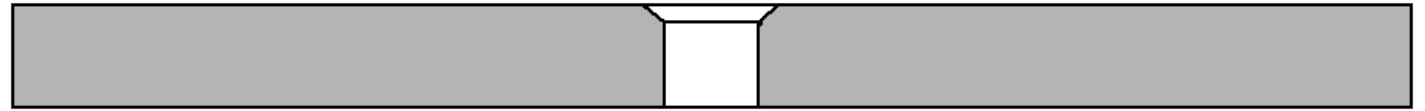
Sample CSK-6



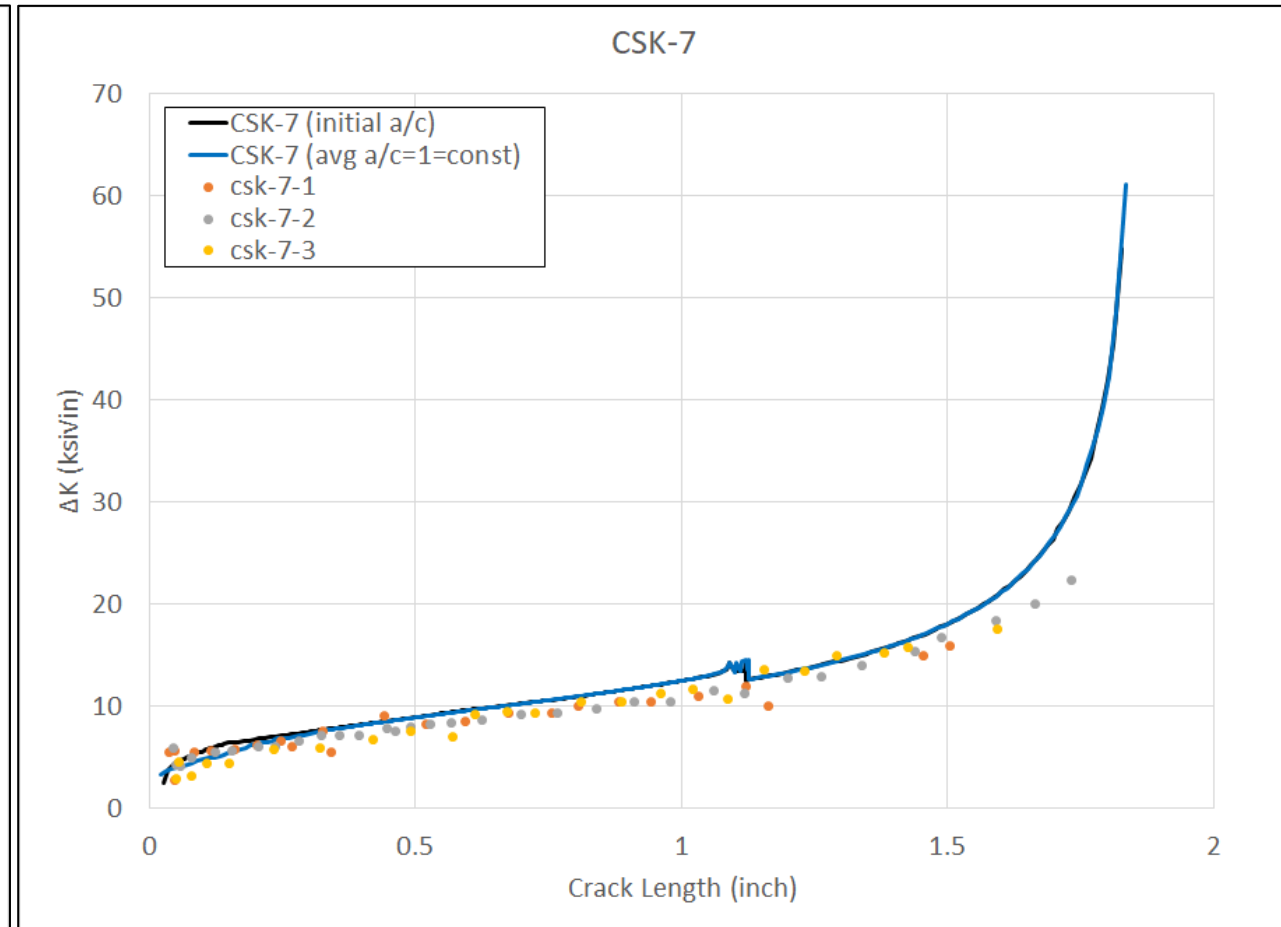
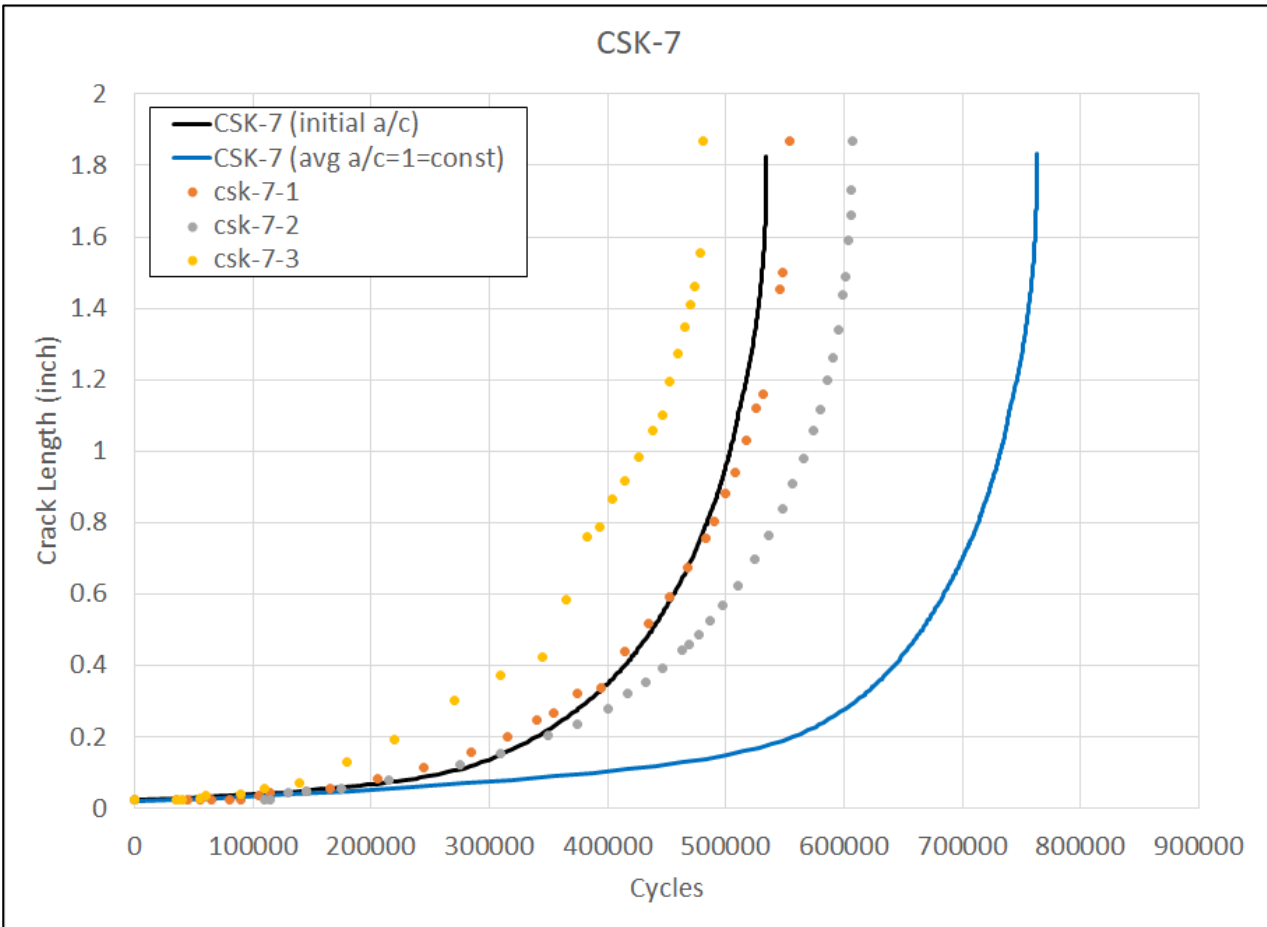
- Updated AFGROW v5.3



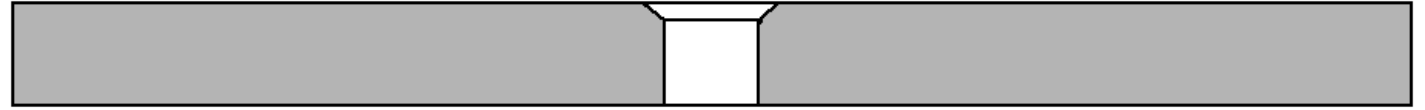
Sample CSK-7



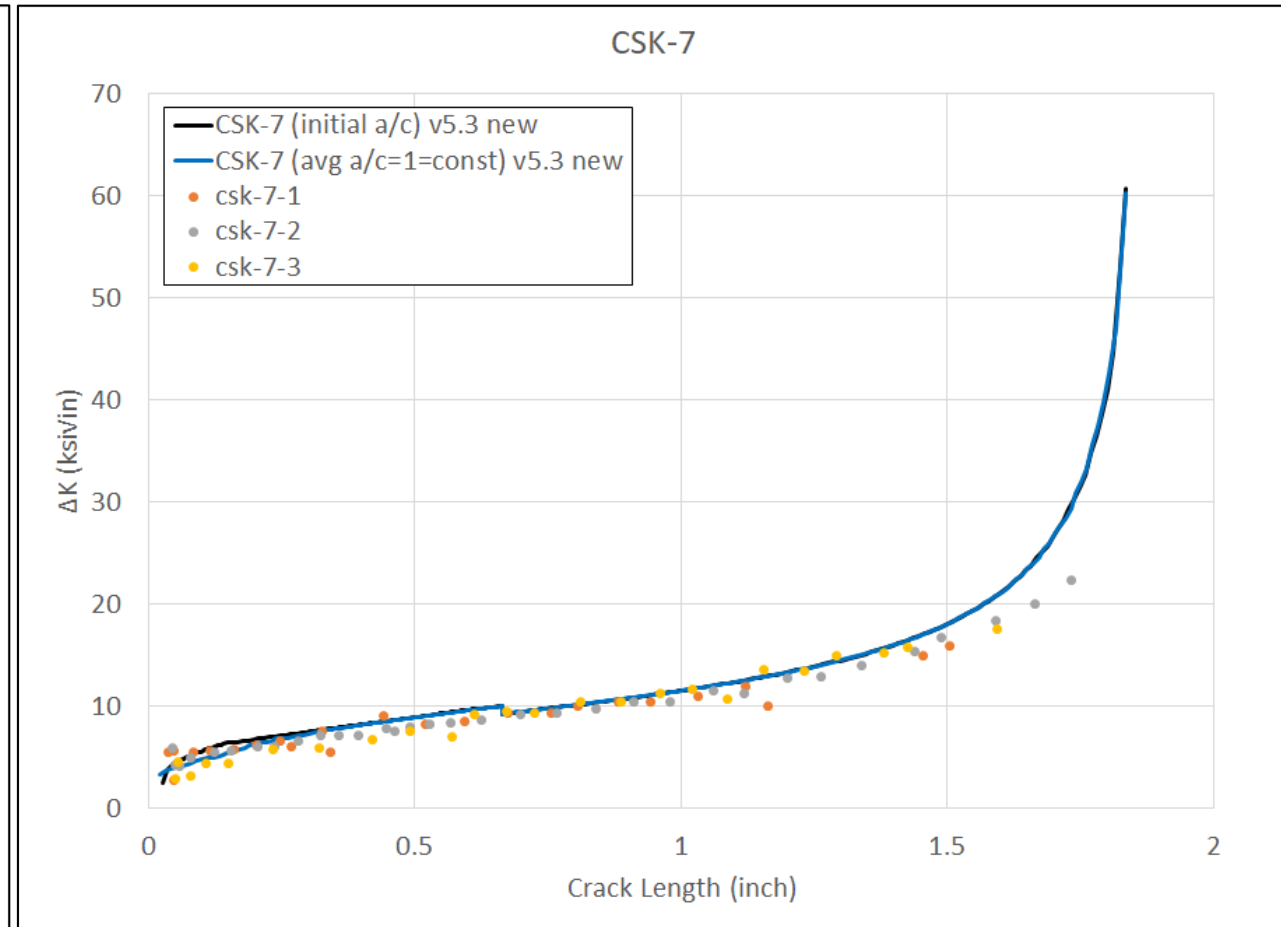
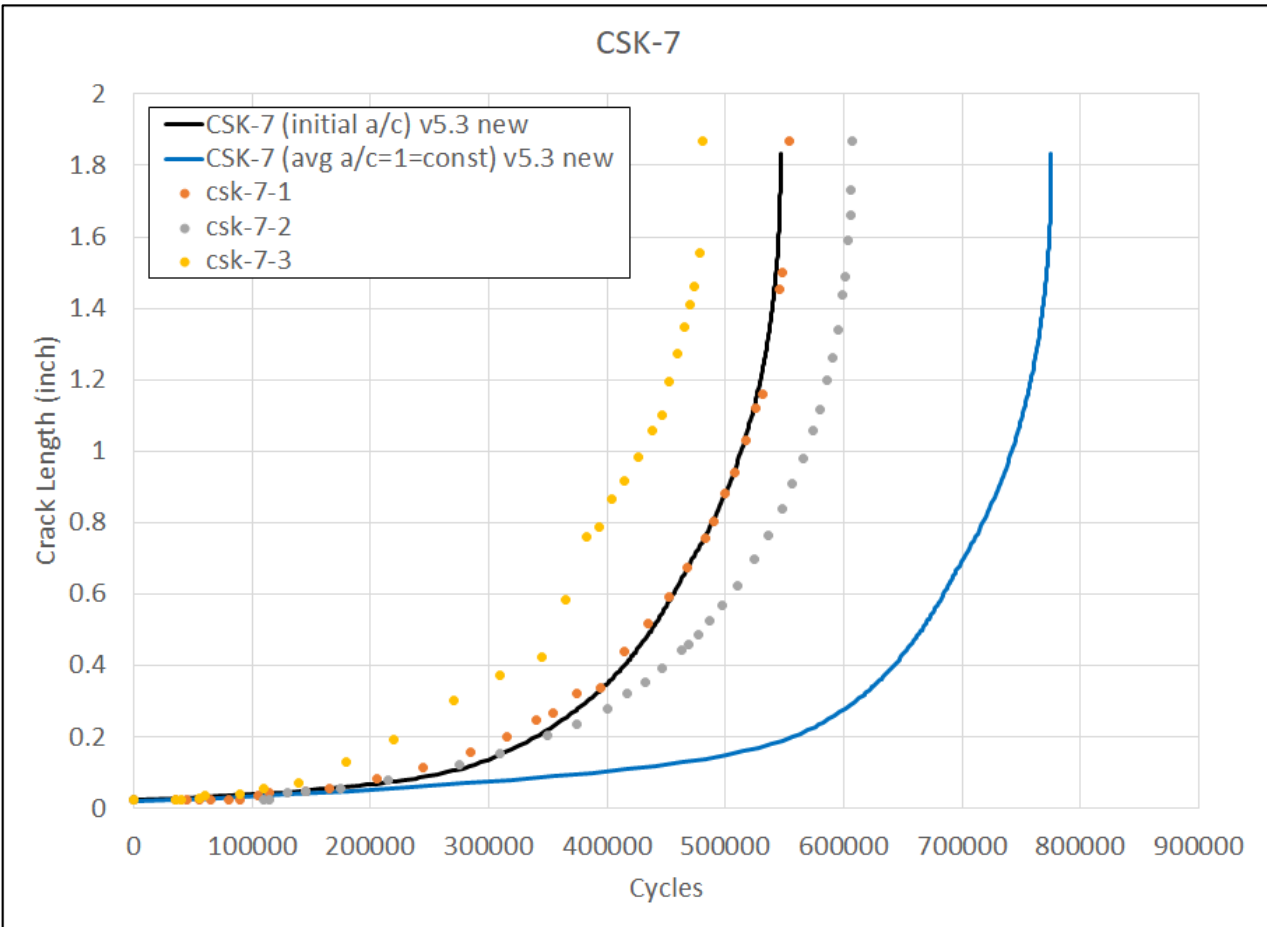
Original AFGROW v5.3



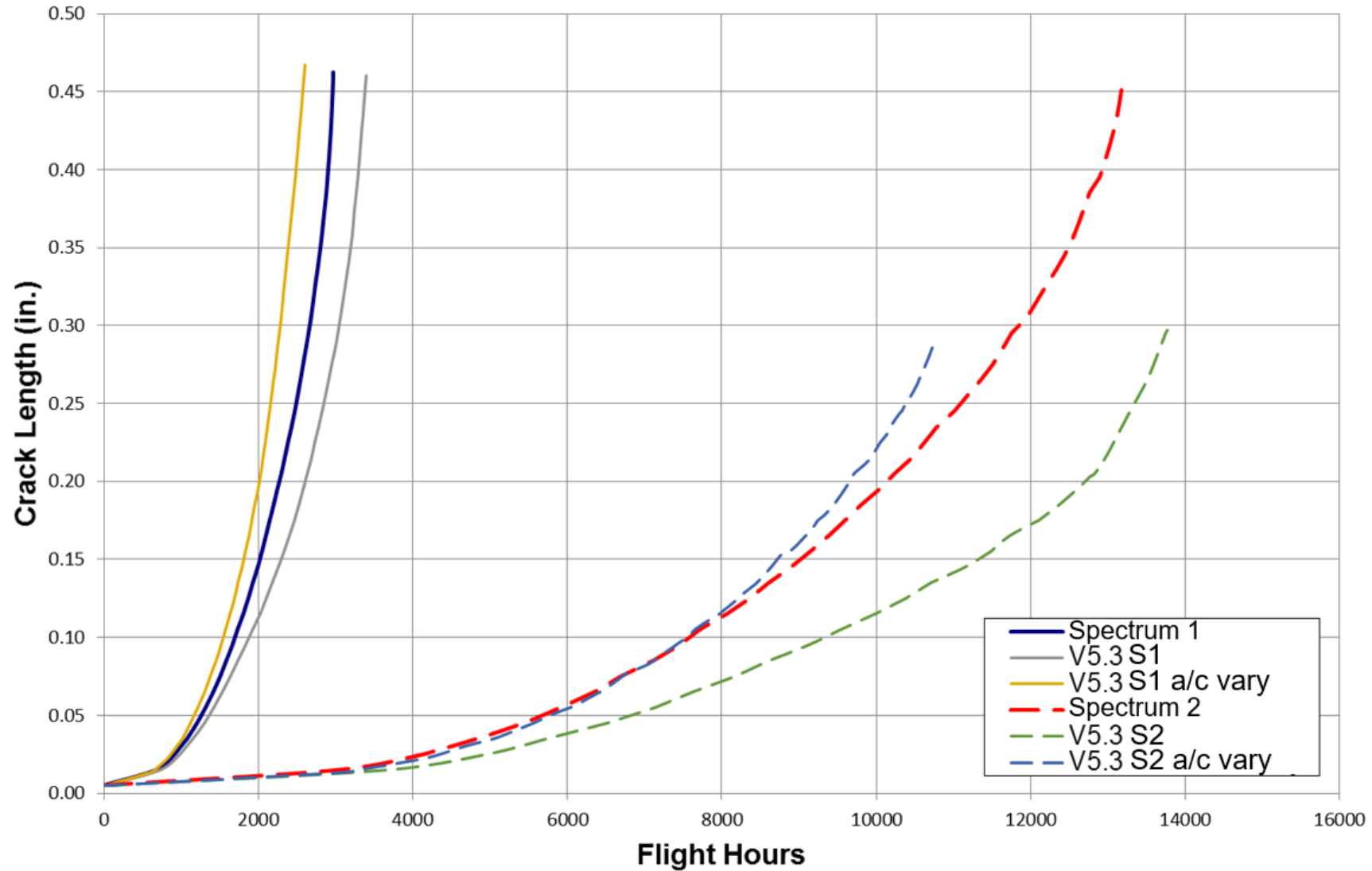
Sample CSK-7



- Updated AFGROW v5.3

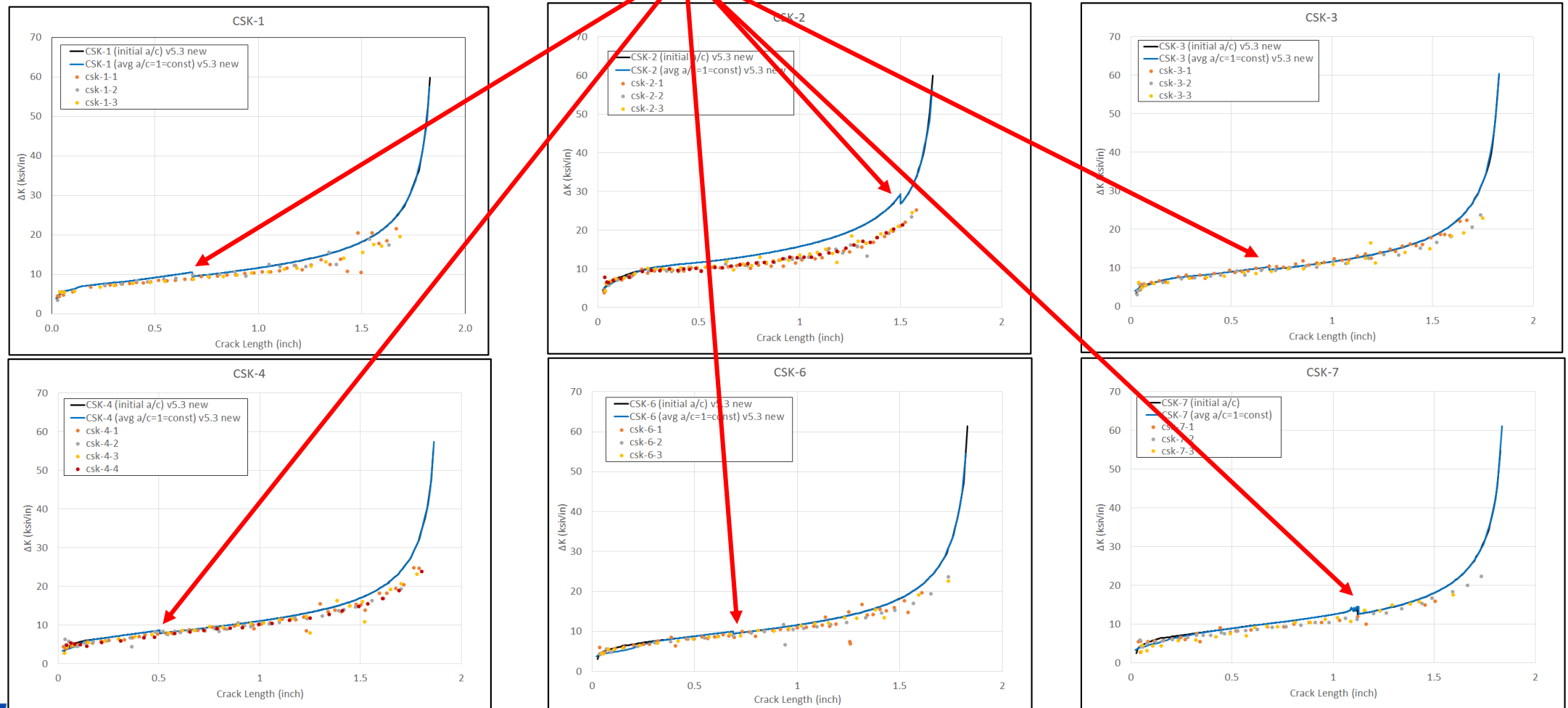


Unknown Aircraft FCL Quick Look



Observations

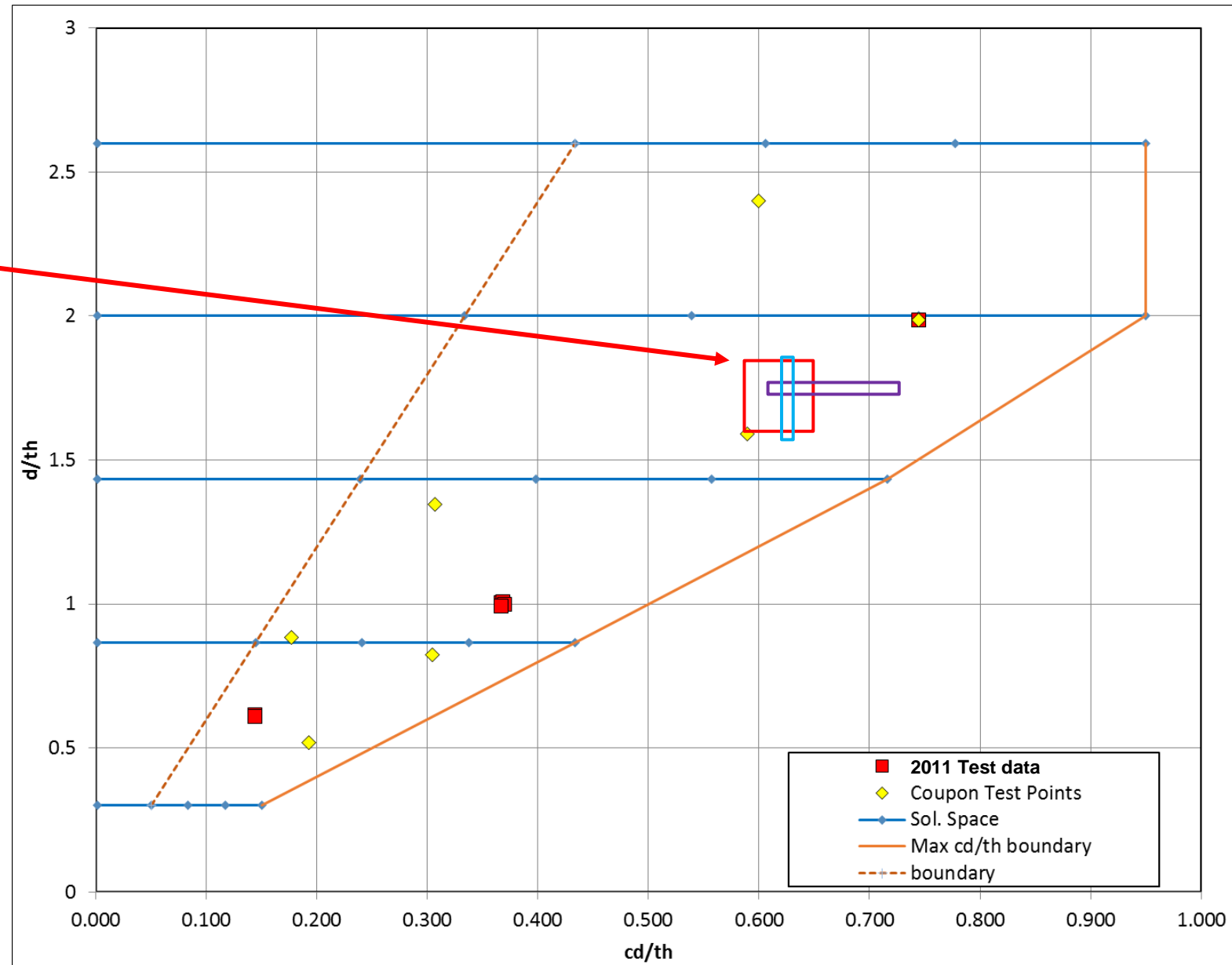
- At these points K_s has reached the a/c limit for solution space, and transitions to AFGROW standard thru crack solution



Observations

- Solution space trouble region for original v5.3
 - Red: vary thickness
 - Purple: vary csk depth
 - Blue: vary hole diameter
- Seem to be fixed in new v5.3

Condition	Hole offset	Plate Thickness	Hole Diameter	Countersunk Depth	d/th	cd/th	
	2	0.165	0.275	0.102	1.667	0.618	right
	2	0.168	0.275	0.102	1.637	0.607	wrong-star
3	2	0.173	0.275	0.102	1.590	0.590	wrong
	2	0.185	0.275	0.102	1.486	0.551	wrong-end
	2	0.186	0.275	0.102	1.478	0.548	right
	2	0.173	0.275	0.09	1.590	0.520	right
	2	0.173	0.275	0.1	1.590	0.578	wrong-star
3	2	0.173	0.275	0.102	1.590	0.590	wrong
	2	0.173	0.275	0.12	1.590	0.694	wrong-end
	2	0.173	0.275	0.121	1.590	0.699	right
	2	0.173	0.254	0.102	1.468	0.590	right
	2	0.173	0.255	0.102	1.474	0.590	wrong-star
3	2	0.173	0.275	0.102	1.590	0.590	wrong
	2	0.173	0.285	0.102	1.647	0.590	wrong-end
	2	0.173	0.29	0.102	1.676	0.590	right



Comments

- 2011 FEA solution space was limited by the surface crack length 'c' < 2.5*Diameter
 - Was this same limitation used in the AFGROW implementation?
 - Based off some of original v5.3 results (CSK-3 and CSK-5), it looks like 2011 solutions may actually be used beyond the surface crack length limit, and only transitions to the standard AFGROW thru crack solution when the a/c limit for 2011 solutions is reached ($0.5 < a/c < 4$)
- An unknown weapon system analyzes 2 different usages
 - The v5.3 critical crack sizes in the Spectrum 2 analysis were much less than the published DTA critical crack size
 - Results in 10% to 20% change in fatigue life
 - From AFGROW output file:
 - *(Countersink depth)/t ratio [0.835897] is outside of the valid range (0.05 <= bot <= 0.5)*
- To Jim, Alex, and LexTech team:
 - What do you need from this group do to help fill in the gaps or help address areas of concern?
 - We are **“here to help”**

End.



September 11 Polish Birthday!

