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LexTech, Inc.

Effect of Grain Orientation on Round Robin Life Predictions

2017 AFGROW Workshop
Round Robin Test Effort

Test Specimens

SAFE ENGINEERING

Specimen Testing

APES, INC.

analytical processes / engineered solutions

Crack Measurements/Data Reduction

SwRI

SOUTHWEST RESEARCH INSTITUTE

Crack Growth Rate Data

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Round Robin Instructions

Round Robin Participants

analytical processes / engineered solutions

SOUTHWEST RESEARCH INSTITUTE

HILL ENGINEERING

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Purpose

Determine the ability to predict the evolution of crack shape and total life of a corner crack at a hole using the same loading spectrum, material data, and a given Initial Flaw Size (IFS),

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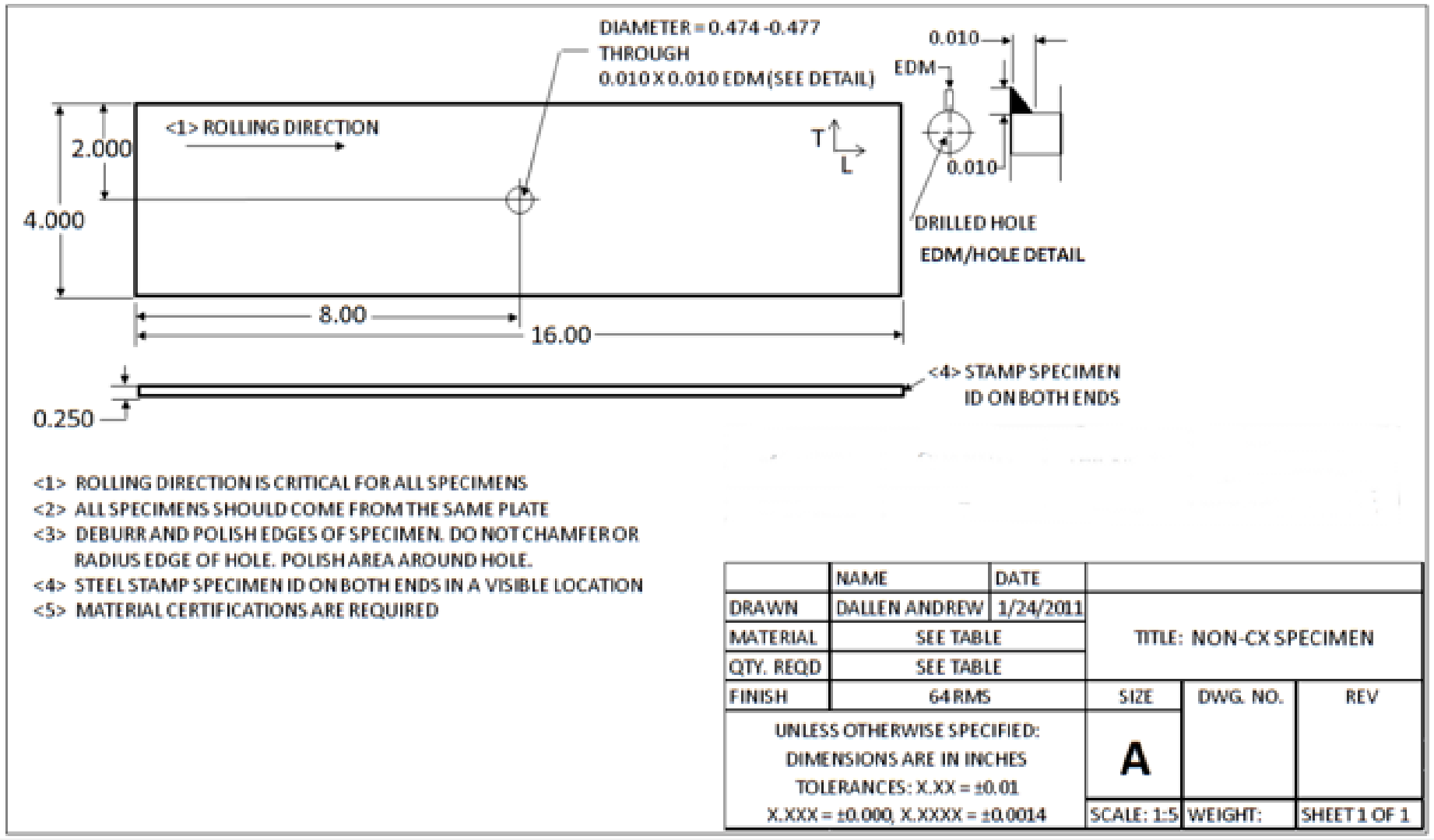
Centered Hole Test Specimen Geometry



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Test Specimen Replicate Data

PC-CX-7075	Max Spectrum Stress		12 ksi				
	Serial	Feature	Description	SwRI Measure	SAFE Measure	Pass?	SAFE Tool Used
	-1	1	Width	4.0070	4.0040	Yes	SAFE Caliper 500-196-30
	-1	2	Thickness	0.2515	0.2511	Yes	SAFE Mike 59/30032
	-1	3	Hole Diameter	0.4757	0.4756	Yes	SAFE Inside Mike 13-576-4
	-1	4	Length	-	16.0250	-	24" Mito Caliper
	-1	7	Notch Width	-	0.0085	-	Nikon Microscope (W/ DRO)
	-1	8	Notch Length	-	0.0244	-	Nikon Microscope (W/ DRO)
	-1		Initial crack (bore)	-	0.0380		Nikon MM-60 (APES)
	-1		Initial crack (surface)	-	0.0262	-	Nikon MM-60 (APES)
	-1		Alternate IC (bore)	-	0.0472	-	Nikon MM-60 (APES)
	-1		Alternate IC (surface)	-	0.0319	-	Nikon MM-60 (APES)
	Max Spectrum Stress		12 ksi				
	Serial	Feature	Description	SwRI Measure	SAFE Measure	Pass?	SAFE Tool Used
	-2	1	Width	4.0070	4.0040	Yes	SAFE Caliper 500-196-30
	-2	2	Thickness	0.2515	0.2511	Yes	SAFE Mike 59/30032
	-2	3	Hole Diameter	0.4757	0.4755	Yes	SAFE Inside Mike 13-576-4
	-2	4	Length	-	16.0330	-	24" Mito Caliper
	-2	7	Notch Width	-	0.0083	-	Nikon Microscope (W/ DRO)
	-2	8	Notch Length	-	0.0218	-	Nikon Microscope (W/ DRO)
	-2		Initial crack (bore)		0.0315		Nikon MM-60 (APES)
	-2		Initial crack (surface)	-	0.0257	-	Nikon MM-60 (APES)
	-2		Alternate IC (bore)	-	0.0384	-	Nikon MM-60 (APES)
	-2		Alternate IC (surface)	-	0.0307	-	Nikon MM-60 (APES)
	Max Spectrum Stress		12 ksi				
	Serial	Feature	Description	SwRI Measure	SAFE Measure	Pass?	SAFE Tool Used
	-3	1	Width	4.0030	4.0030	Yes	SAFE Caliper 500-196-30
	-3	2	Thickness	0.2510	0.2511	Yes	SAFE Mike 59/30032
	-3	3	Hole Diameter	0.4758	0.4751	Yes	SAFE Inside Mike 13-576-4
	-3	4	Length	-	16.0310	-	24" Mito Caliper
	-3	7	Notch Width	-	0.0078	-	Nikon Microscope (W/ DRO)
	-3	8	Notch Length	-	0.0200	-	Nikon Microscope (W/ DRO)
	-3		Initial crack (bore)		0.0313		Nikon MM-60 (APES)
	-3		Initial crack (surface)	-	0.0255	-	Nikon MM-60 (APES)
	-3		Alternate IC (bore)	-	0.0521	-	Nikon MM-60 (APES)
	-3		Alternate IC (surface)	-	0.0354	-	Nikon MM-60 (APES)

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Test Spectrum

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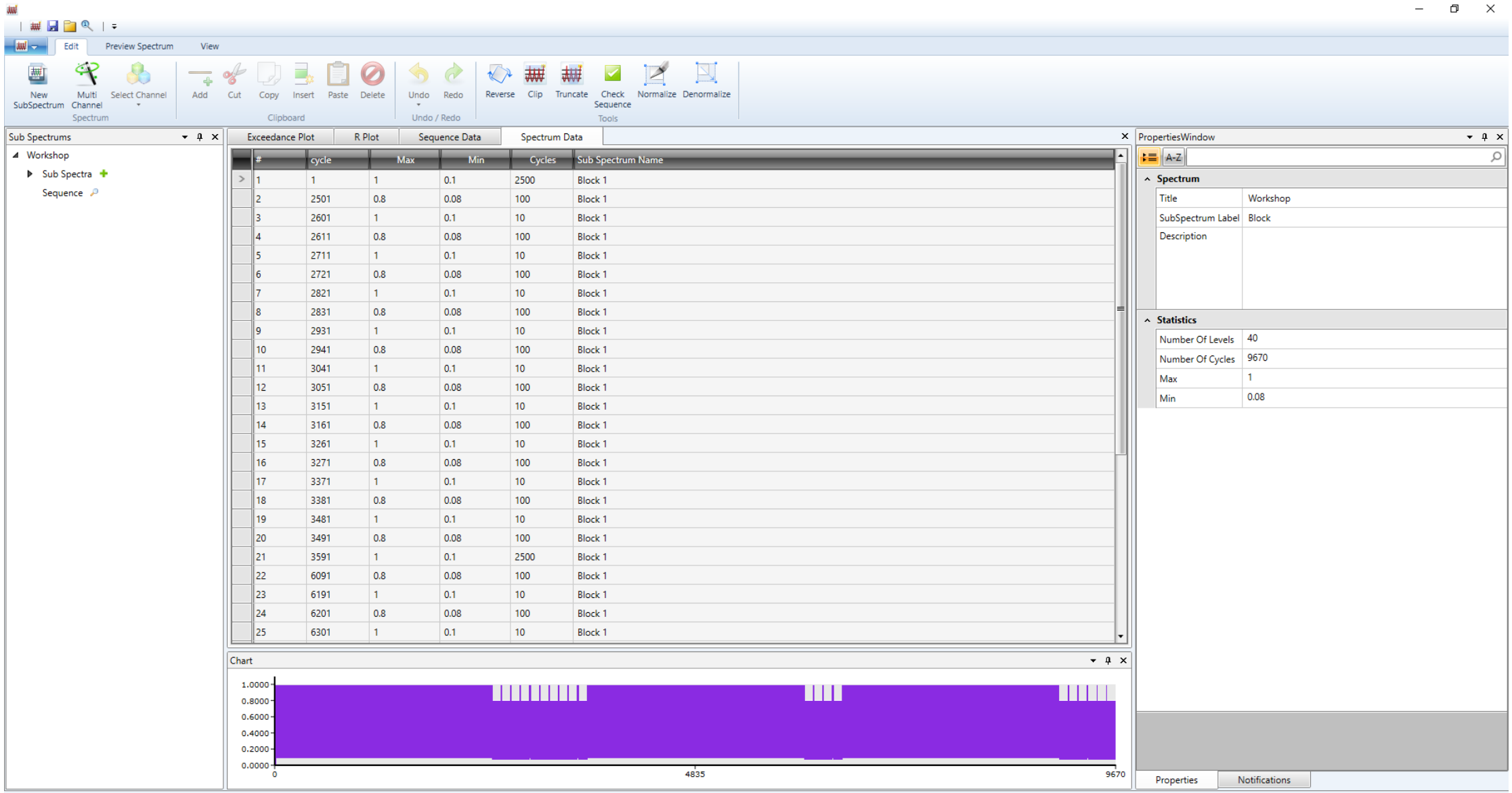

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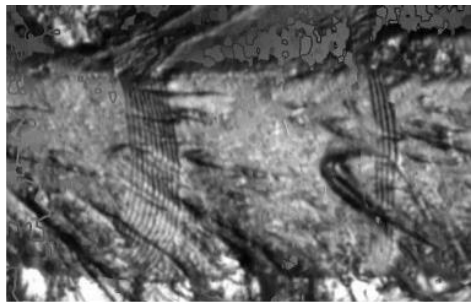
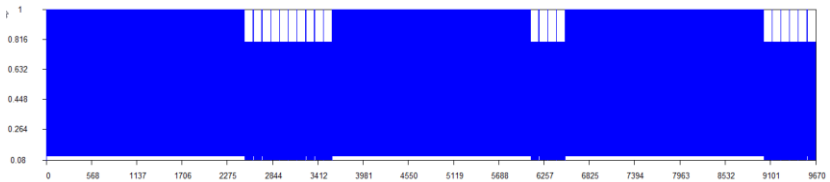
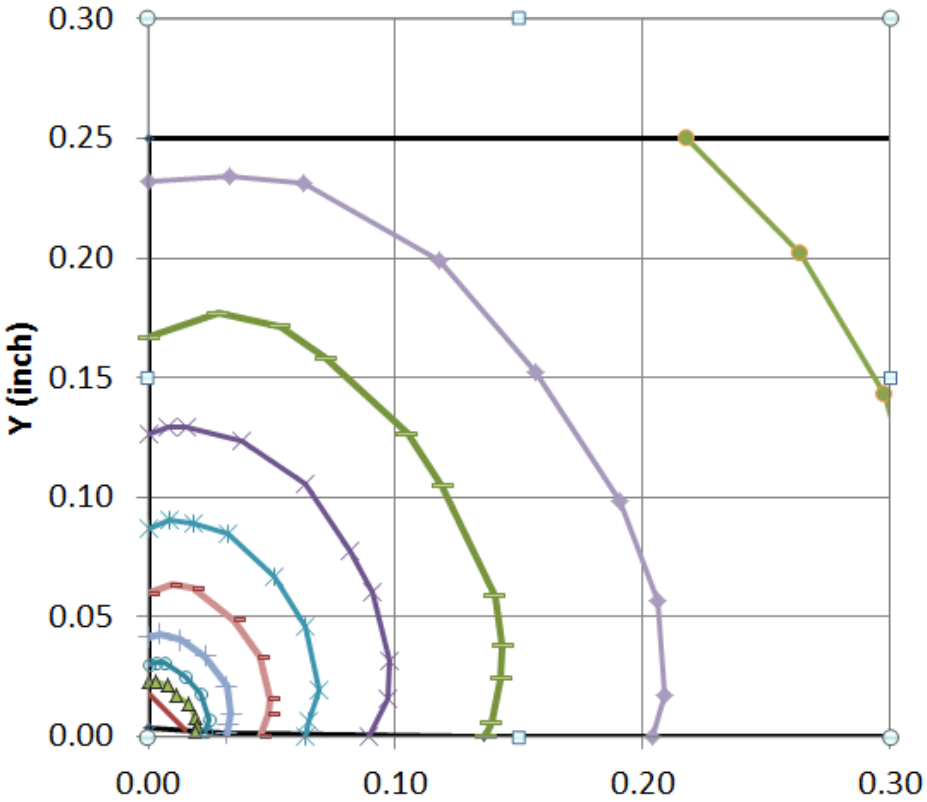
Marking load sequence used to capture crack length and aspect ratio data







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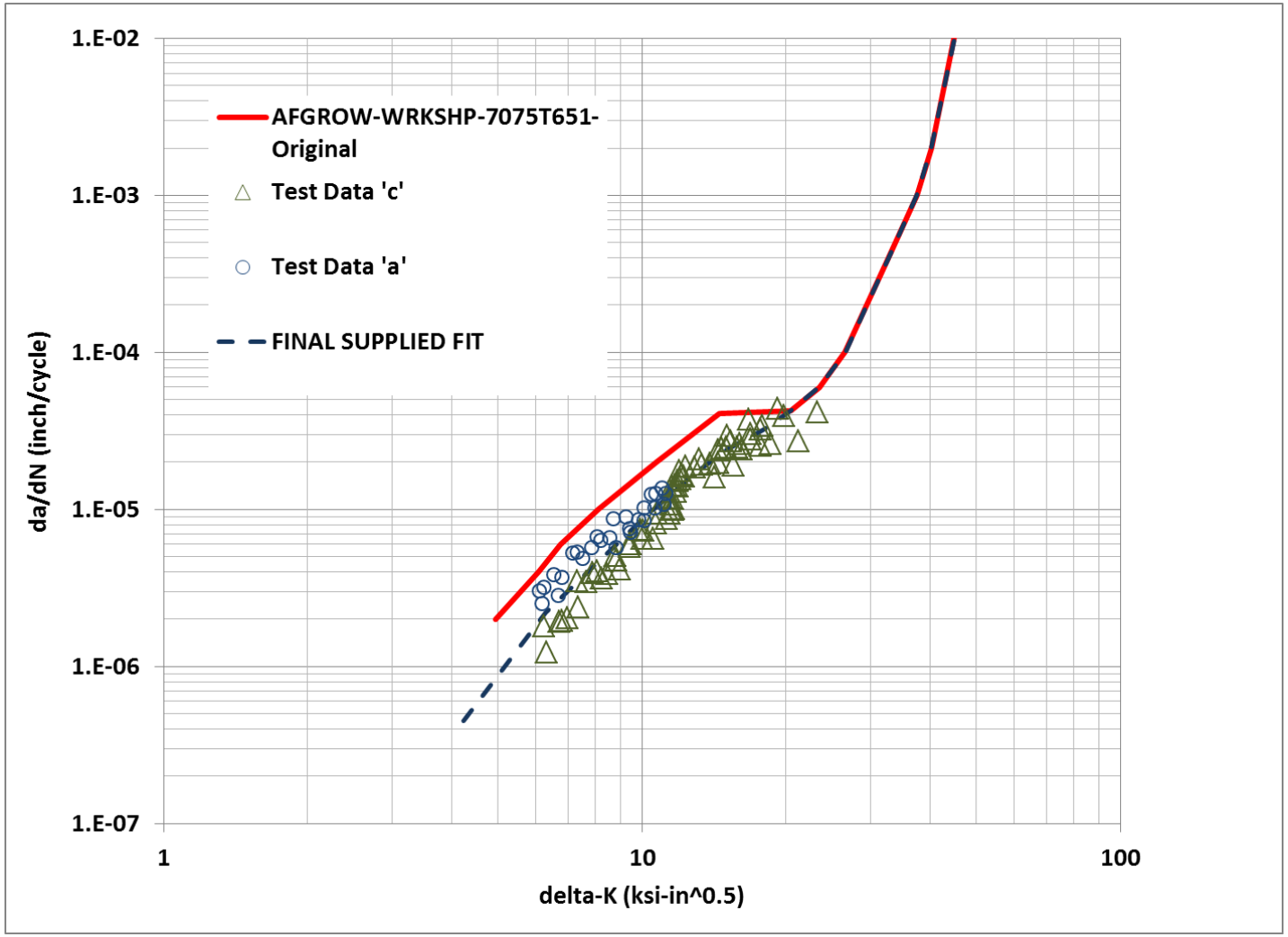
Crack Growth Rate Data



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Participants

	MacAllan - A	MacAllan - B	MacAllan - C	Dalwhinne	FinLaggan	Black Label	Dewars	Jura	Cathead
K-Solution - Center K-Solution - Offset	Two Point Advanced	Two Point Advanced	Two Point Advanced	Advance Classic	FEA	Advanced w/β Correction	FEA Advanced	Unknown	Unknown
Load Interaction	None	Hsu	Hsu, β_R	β_R	None	None	None	Unknown	Unknown
a/c constant	No	No	No	No	No	No	No	No	No

Life Prediction Results

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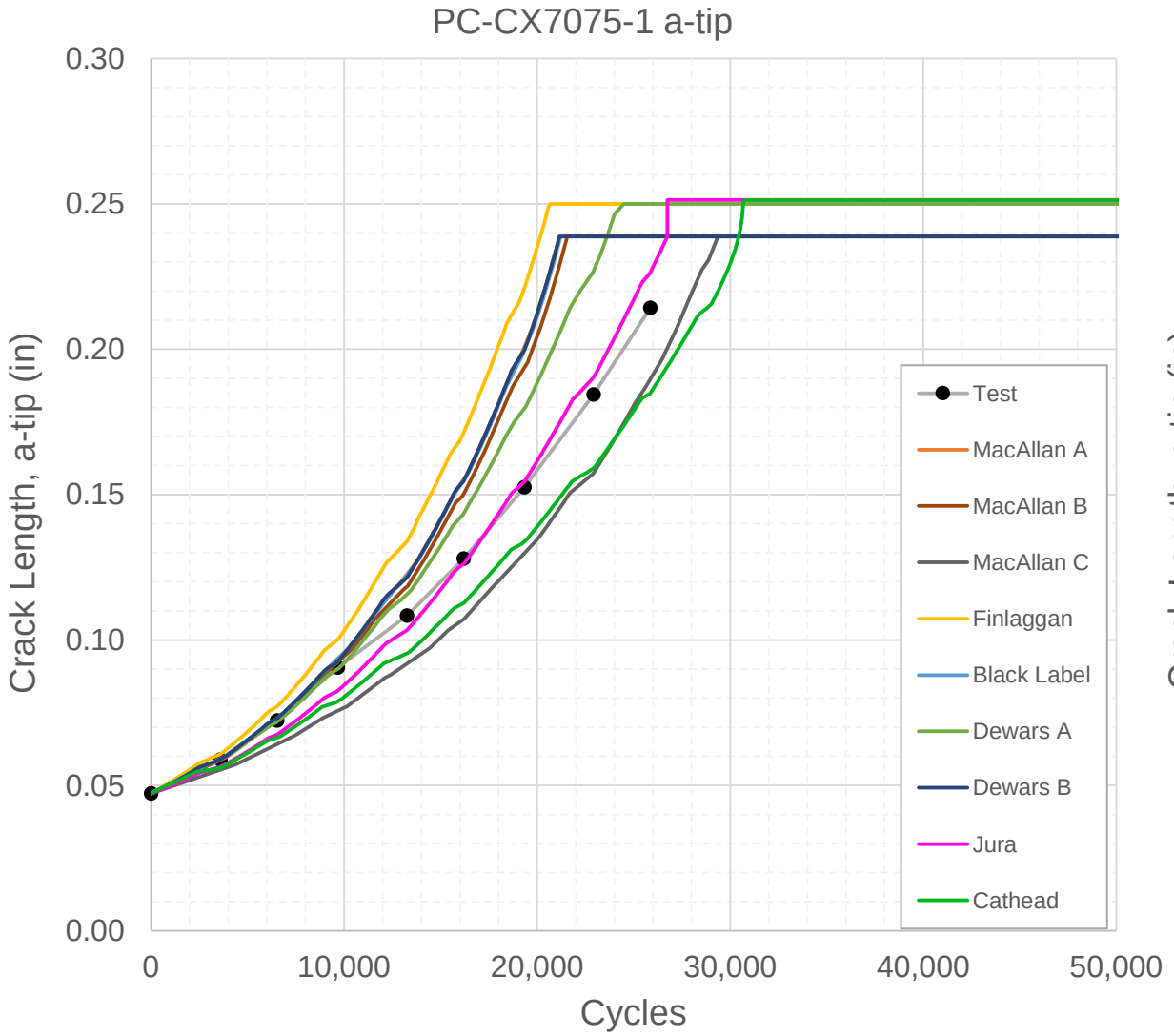

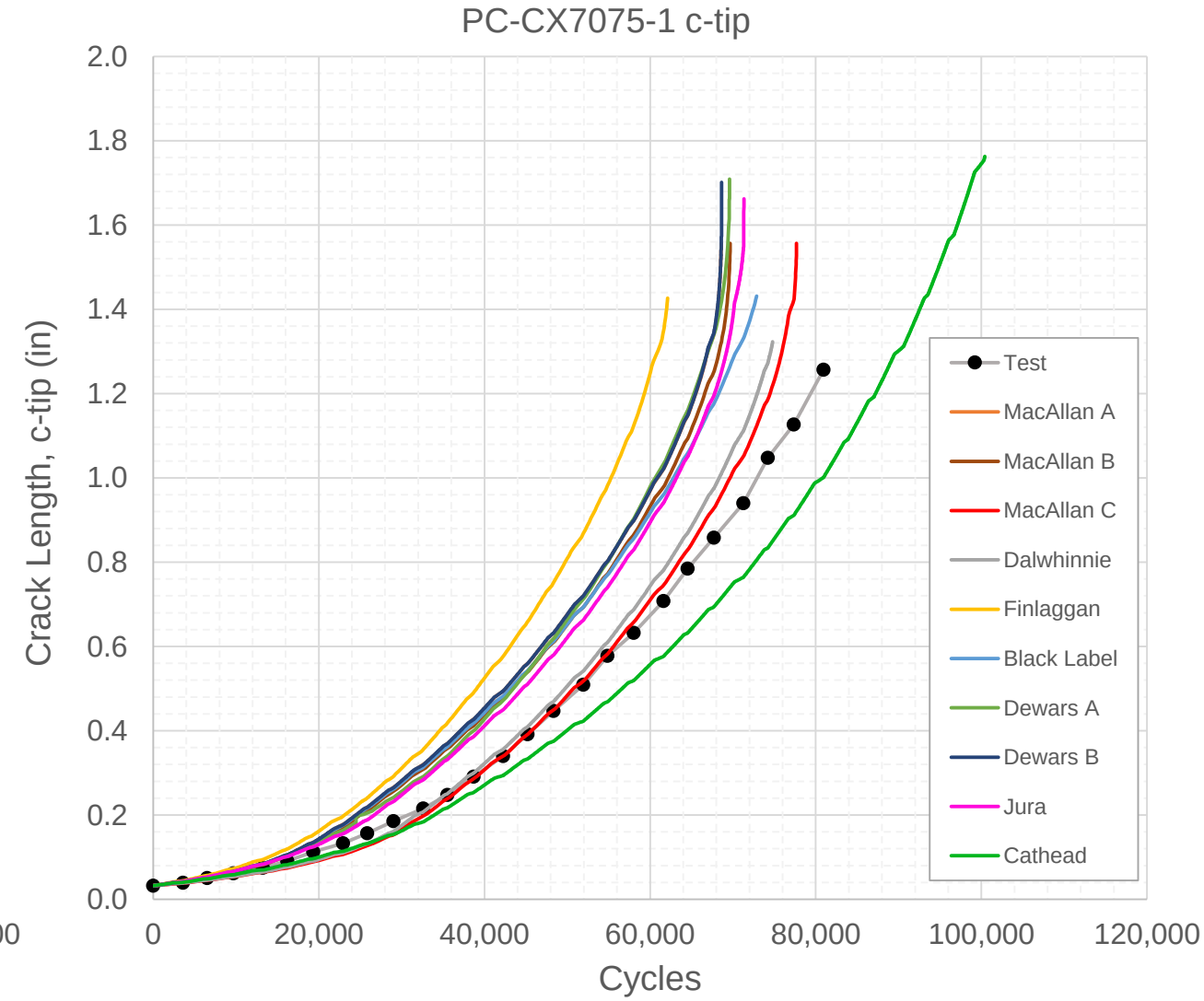

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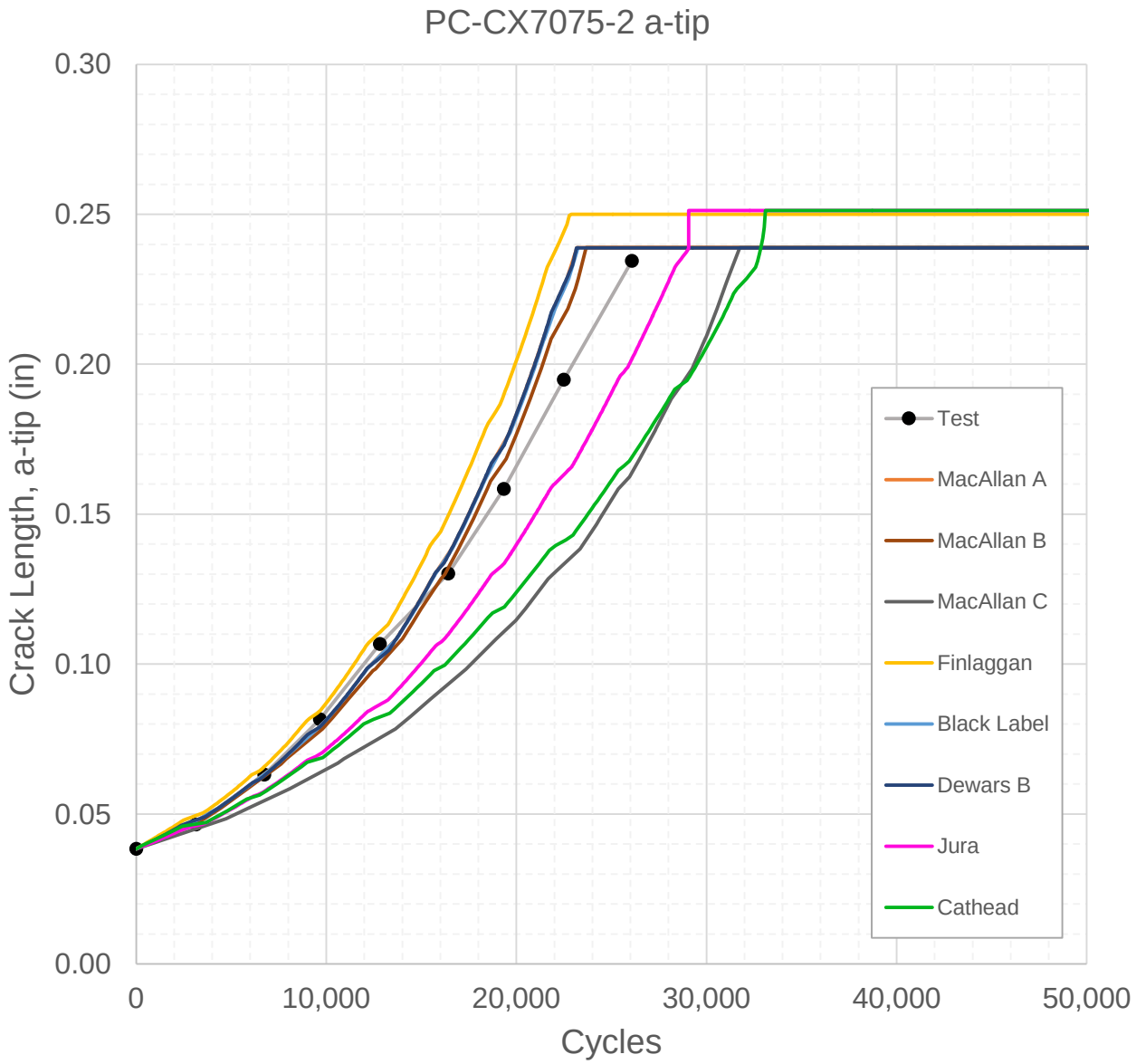

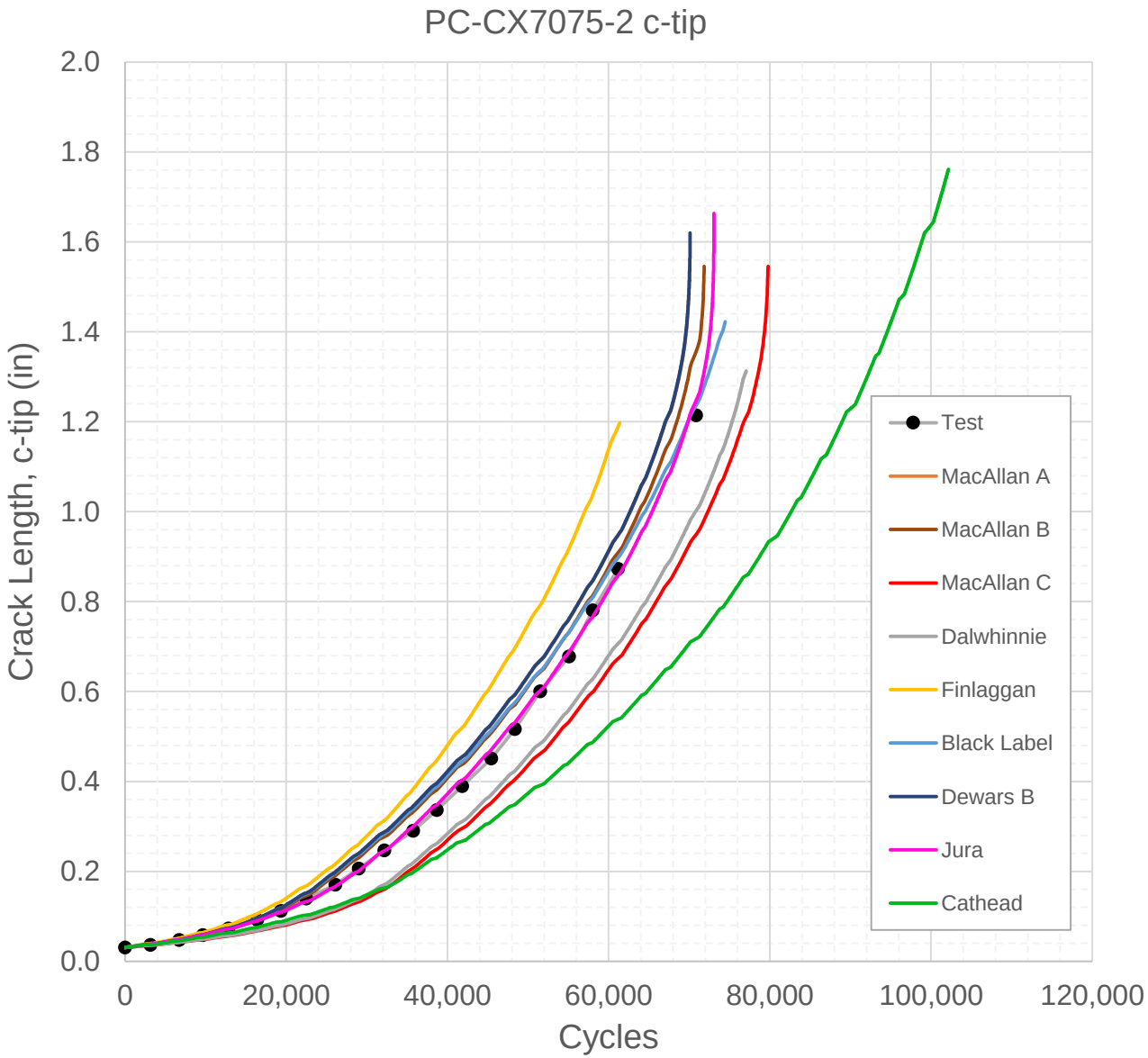

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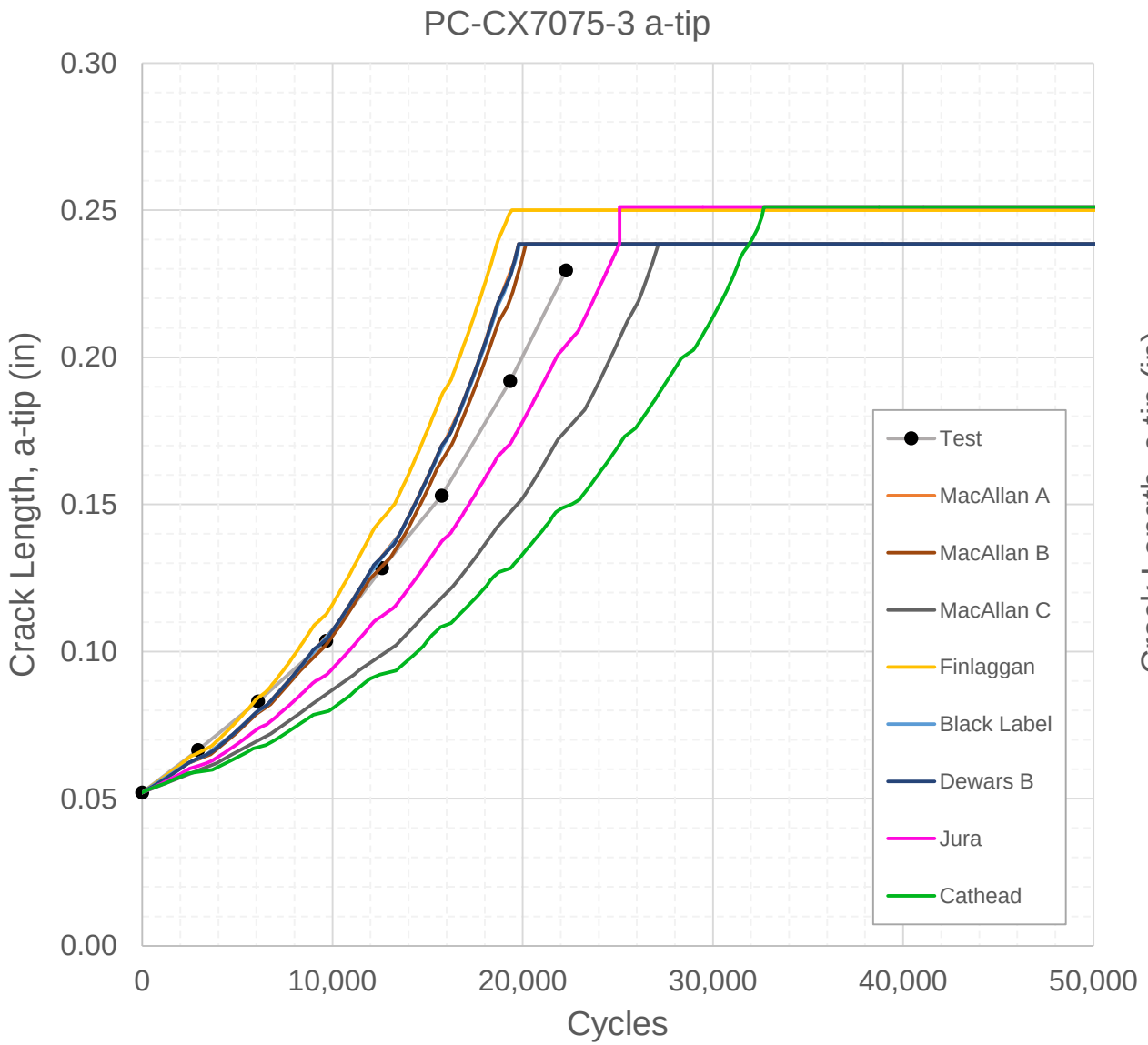

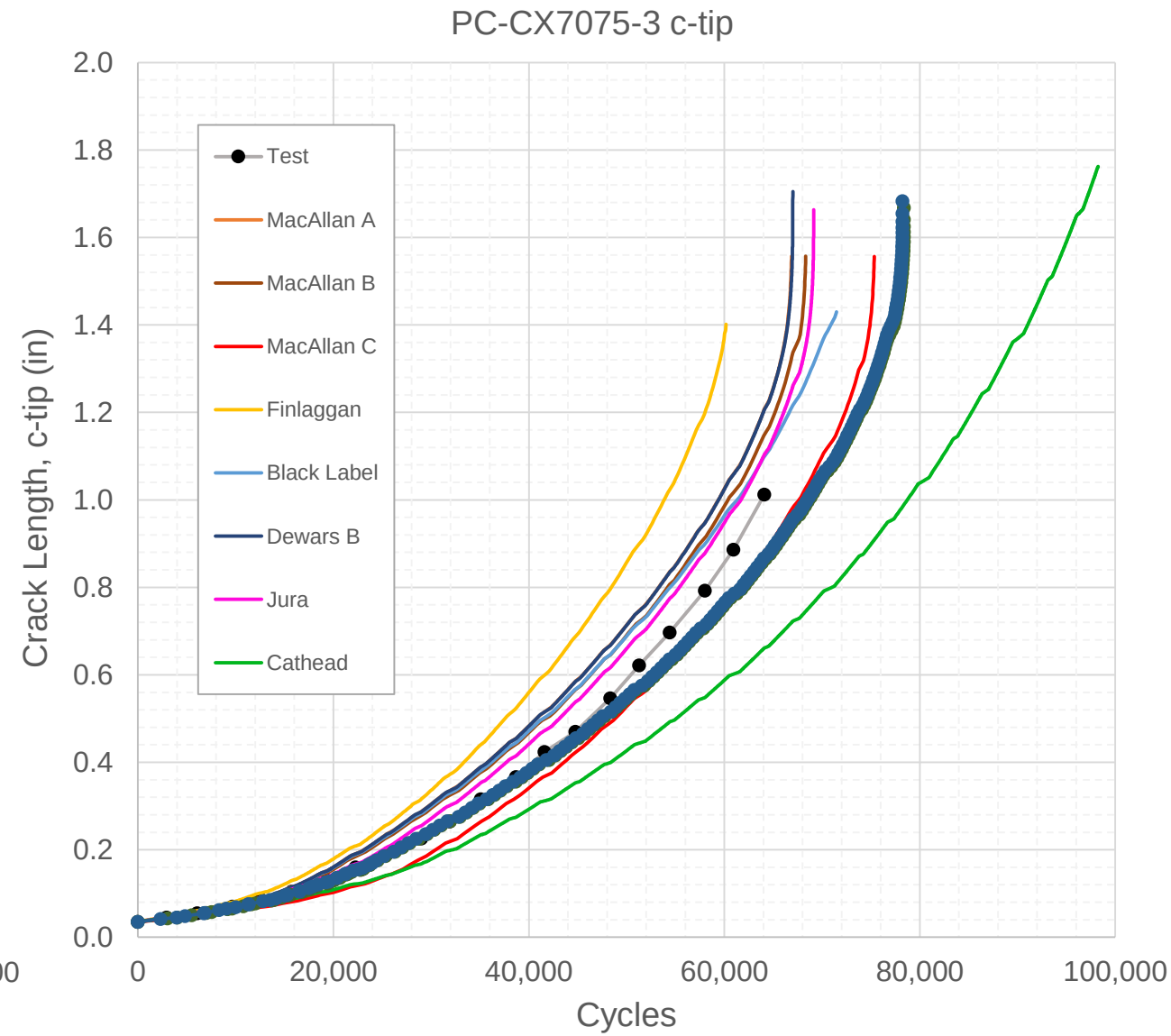

Crack Shape Results

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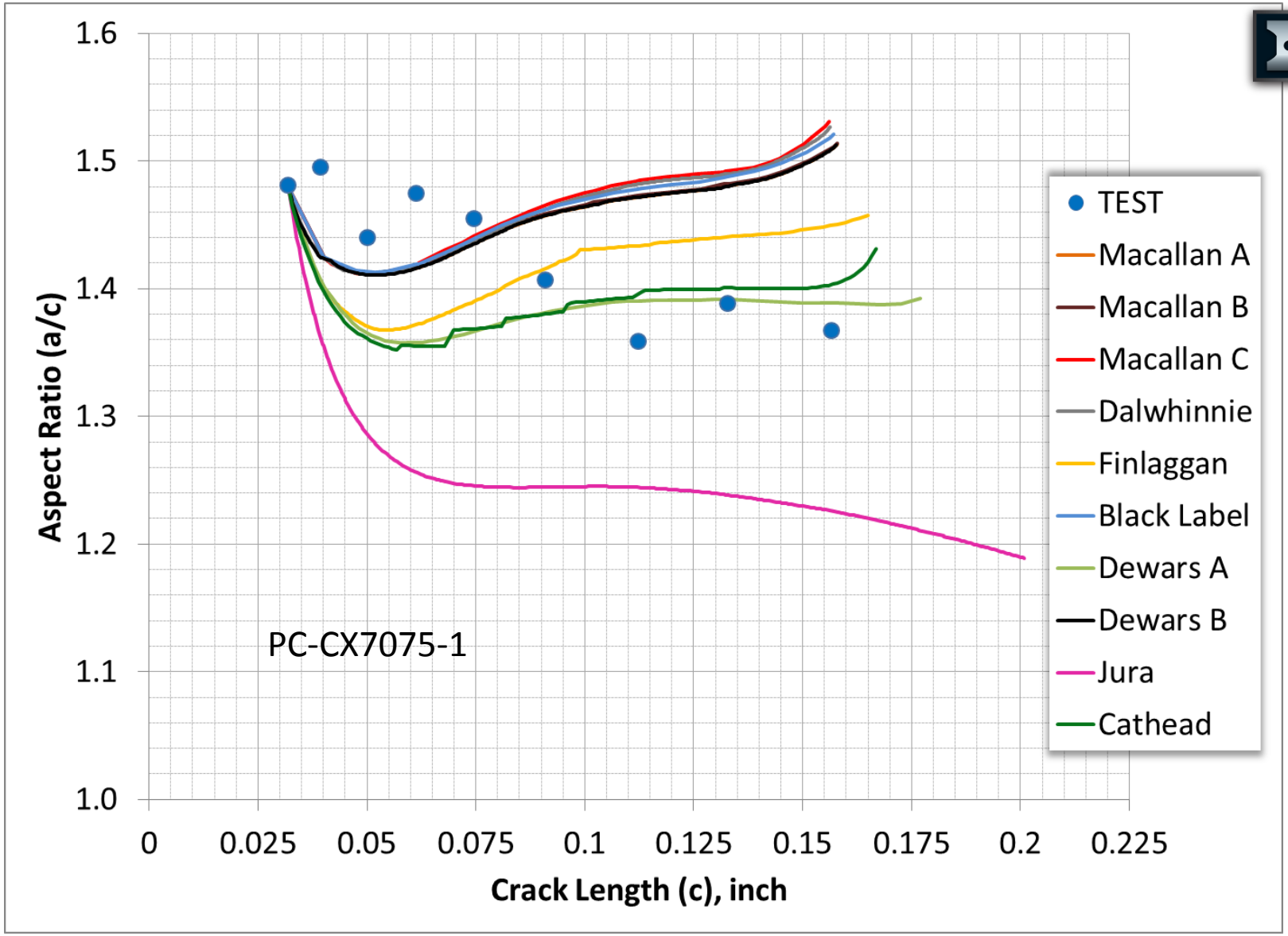

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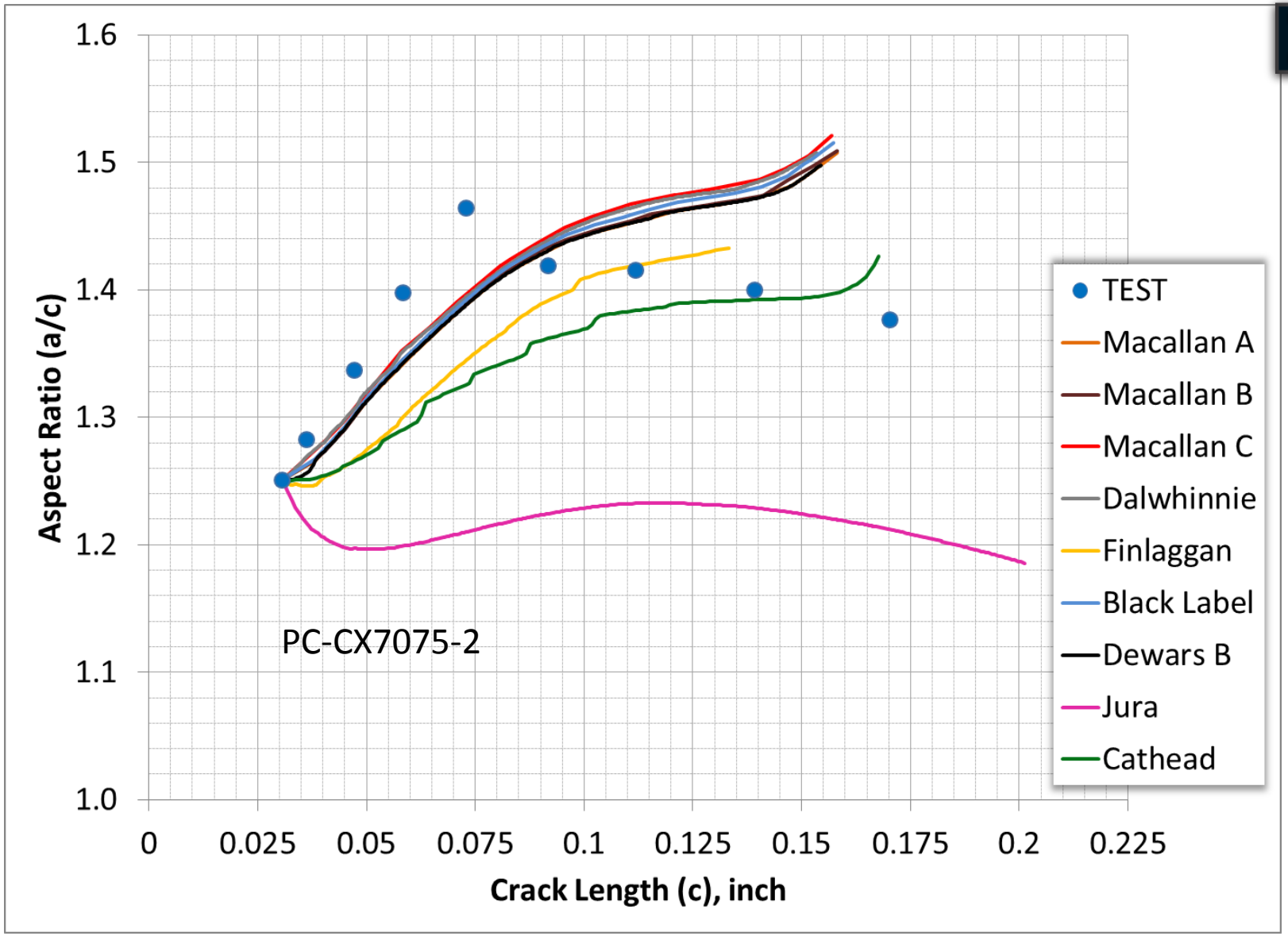

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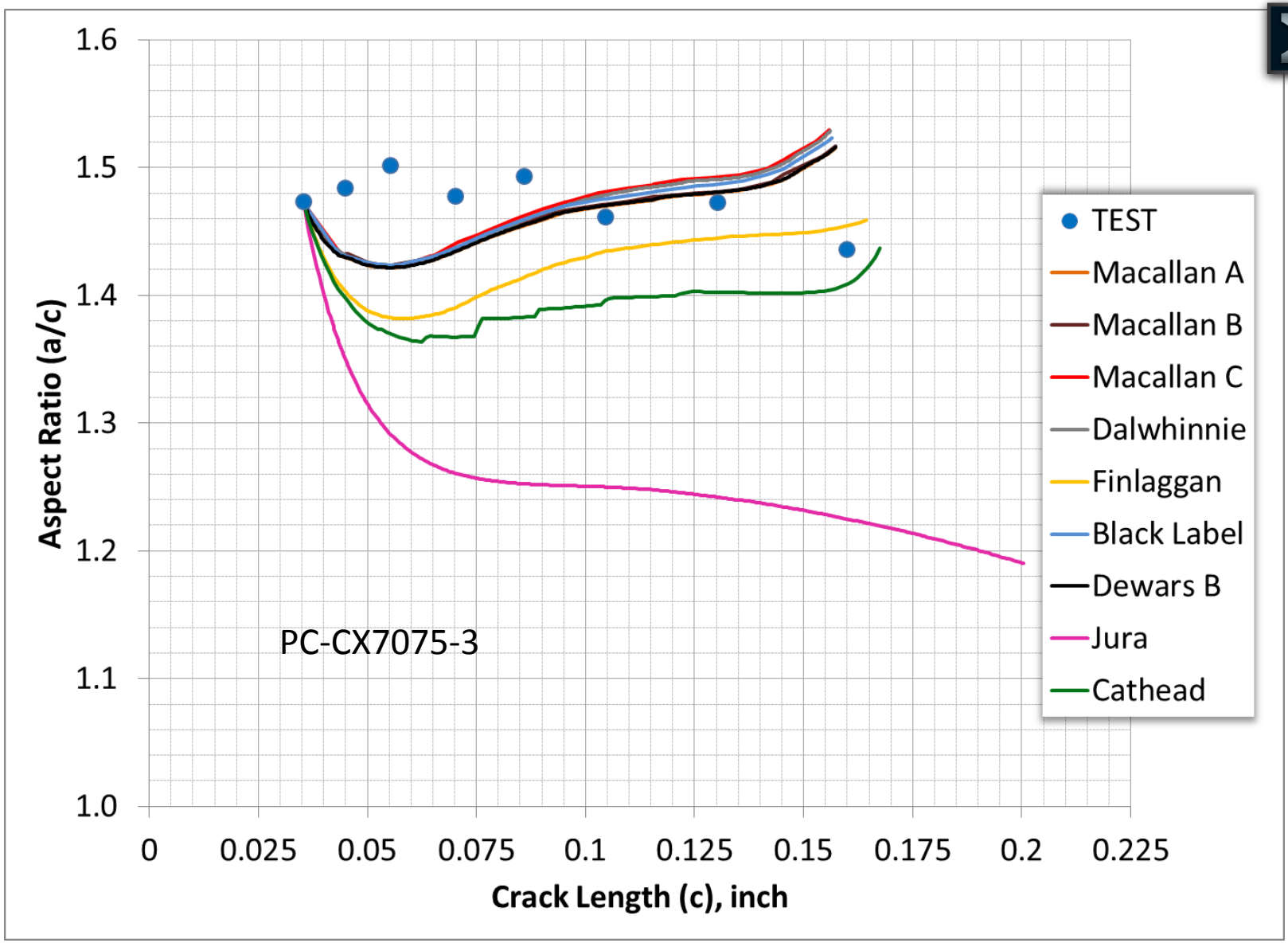

Issues

Life predictions were generally very good, but the crack shape predictions did not follow the trends in the test data

Most of the crack shape predictions converged at a/c ~ 1.5, while the tests converged at ~ 1.4

The crack shape prediction curves crossed the test data points

All predictions were made using a single crack growth rate model for each growth direction

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Single vs. Dual Crack Growth Rate Curve Fits

Single Growth Rate Curve Fit: A single crack growth rate curve fit is used to predict growth in both directions (a and c-directions)

Dual Growth Rate Curve Fit: Two crack growth rate curve fits are used to predict crack growth. One curve fit model is used for the a-direction, and a different model is used for the c-direction

Revisiting the Crack Growth Rate Data

Using Tom Mills' digitized crack length data and two methods for calculating ΔK

Fawaz/Andersson

Newman/Raju

Fawaz/Andersson Example:

Dual Crack Growth Rate From Specimen Striation Measurements

C	A	Cycles	DKc	DKa	Ave DKc	Ave DKa	dc/dN	da/dN
0.0257	0.0315	0	5.9667	6.3408				
0.0307	0.0384	2930	6.3965	6.8736	6.1816	6.6072	1.689E-06	2.365E-06
0.0363	0.0465	6080	6.7938	7.4638	6.5952	7.1687	1.768E-06	2.575E-06
0.0472	0.0632	9670	7.4622	8.4680	7.1280	7.9659	3.058E-06	4.641E-06
0.0583	0.0815	12600	8.1127	9.2580	7.7875	8.8630	3.788E-06	6.276E-06
0.0728	0.1067	15750	8.8441	10.1960	8.4784	9.7270	4.603E-06	7.971E-06
0.0918	0.1302	19340	9.4927	11.2310	9.1684	10.7135	5.273E-06	6.565E-06
0.1120	0.1584	22270	10.2430	12.1780	9.8679	11.7045	6.891E-06	9.631E-06
0.1392	0.1948	25420	11.1600	13.3670	10.7015	12.7725	8.641E-06	1.154E-05
0.1703	0.2344	29010	11.9490	15.9650	11.5545	14.6660	8.671E-06	1.104E-05
0.2058		31940	12.3780		12.1635		1.213E-05	
0.2462		35090	12.6510		12.5145		1.282E-05	
0.2904		38680	12.9590		12.8050		1.230E-05	
0.3365		41610	13.2950		13.1270		1.573E-05	
0.3897		44760	13.7010		13.4980		1.691E-05	
0.4511		48350	14.1900		13.9455		1.709E-05	
0.5162		51280	14.7310		14.4605		2.224E-05	
0.6006		54430	15.4690		15.1000		2.677E-05	
0.6779		58020	16.1860		15.8275		2.153E-05	
0.7802		60950	17.2090		16.6975		3.491E-05	
0.8730		64100	18.2340		17.7215		2.947E-05	

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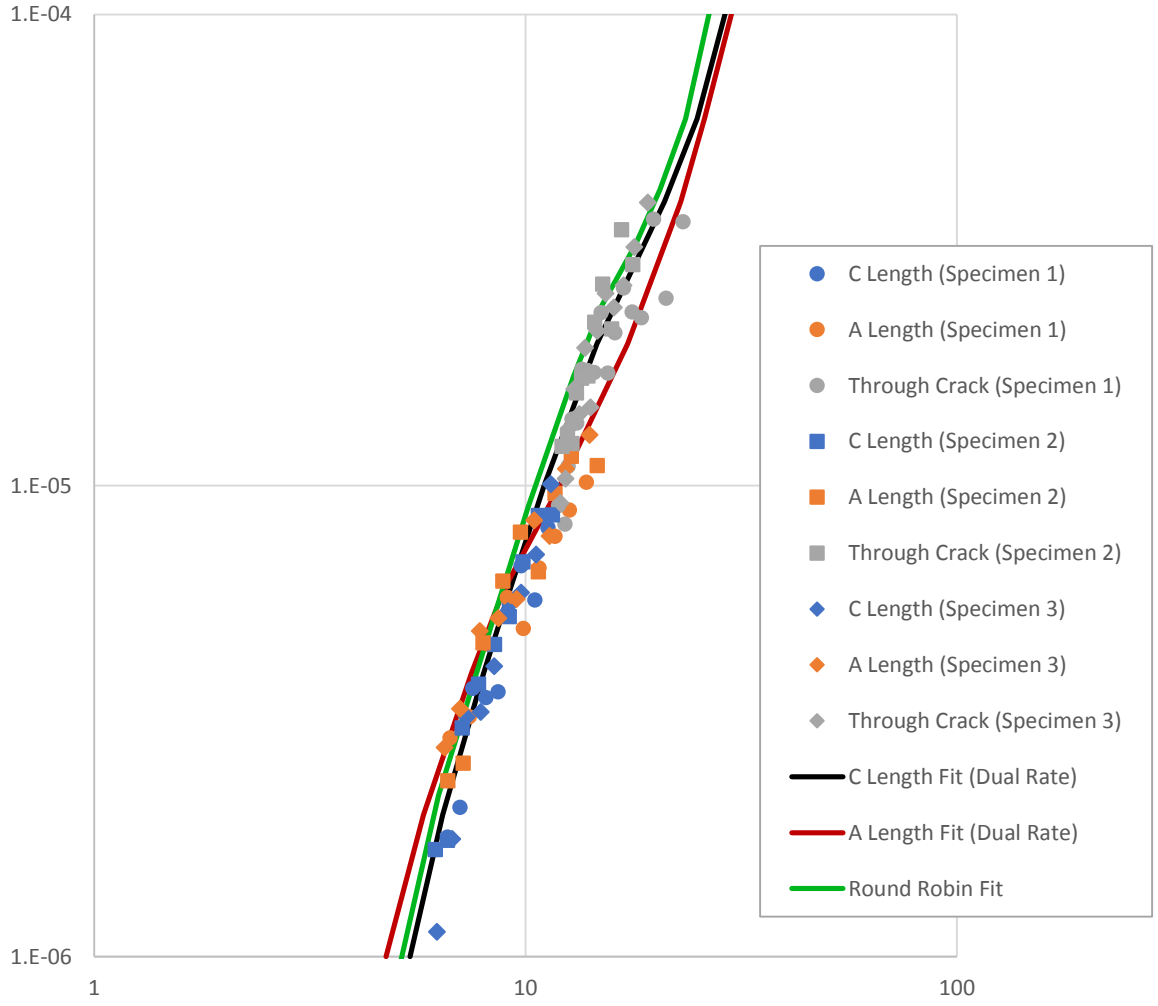
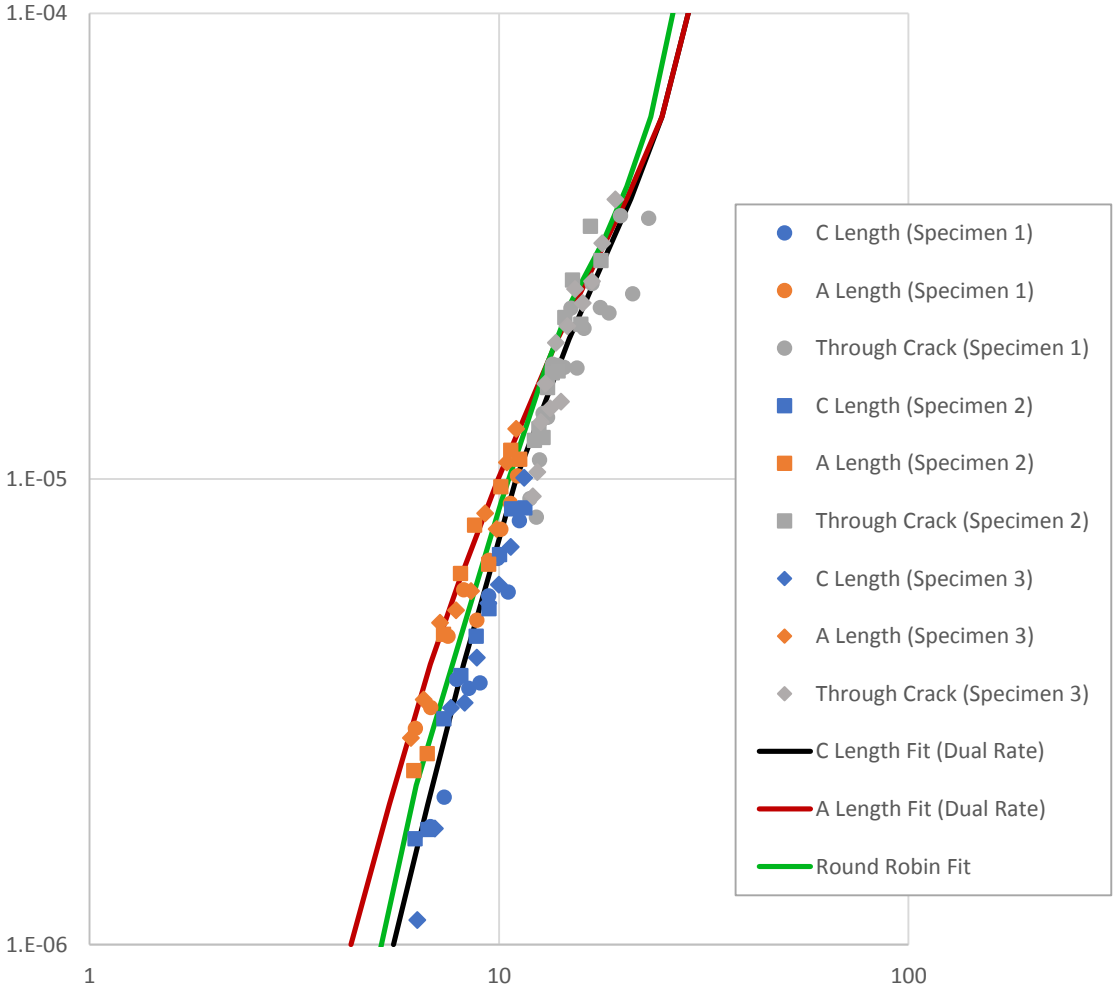
Fawaz/Andersson



Newman/Raju



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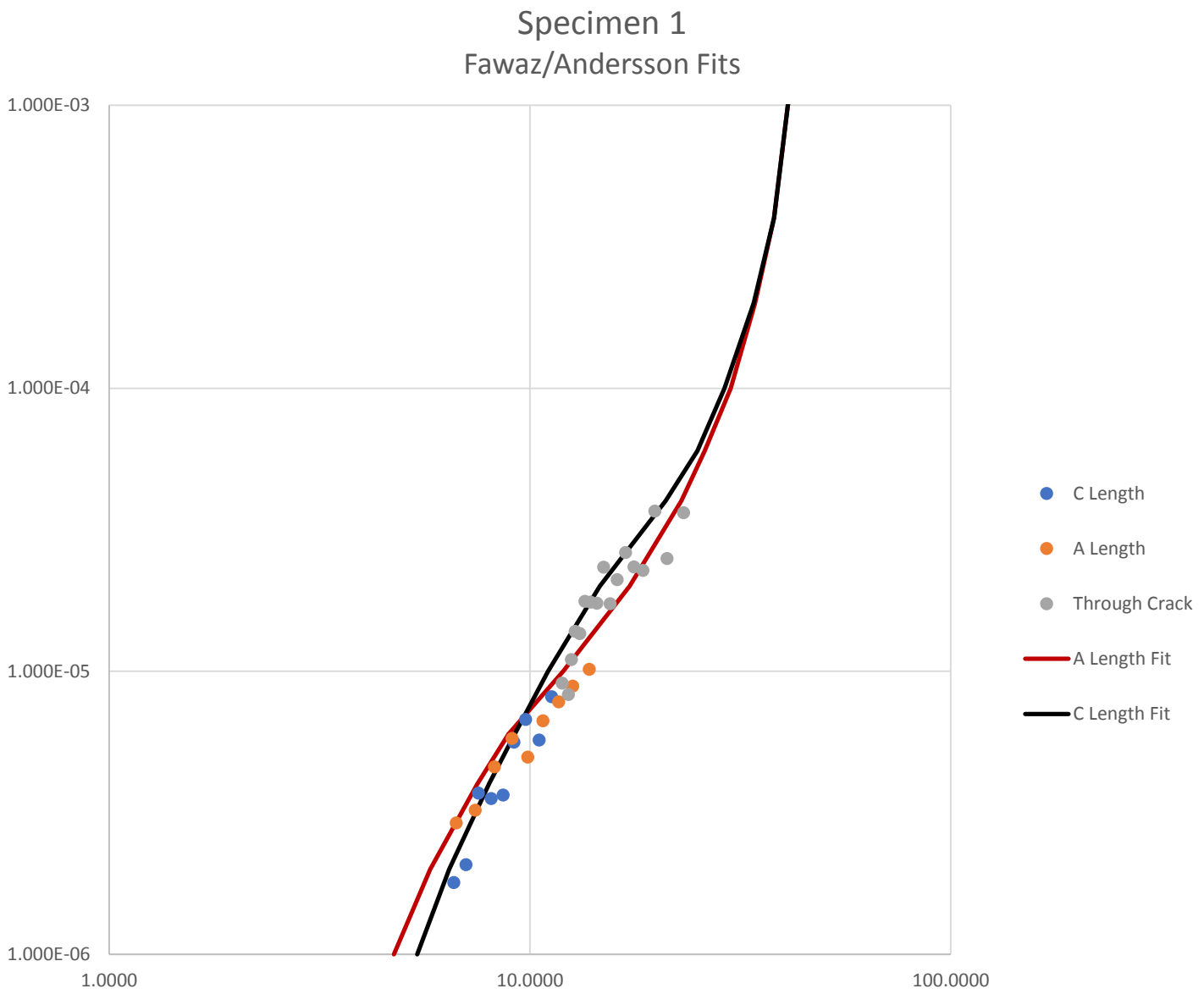

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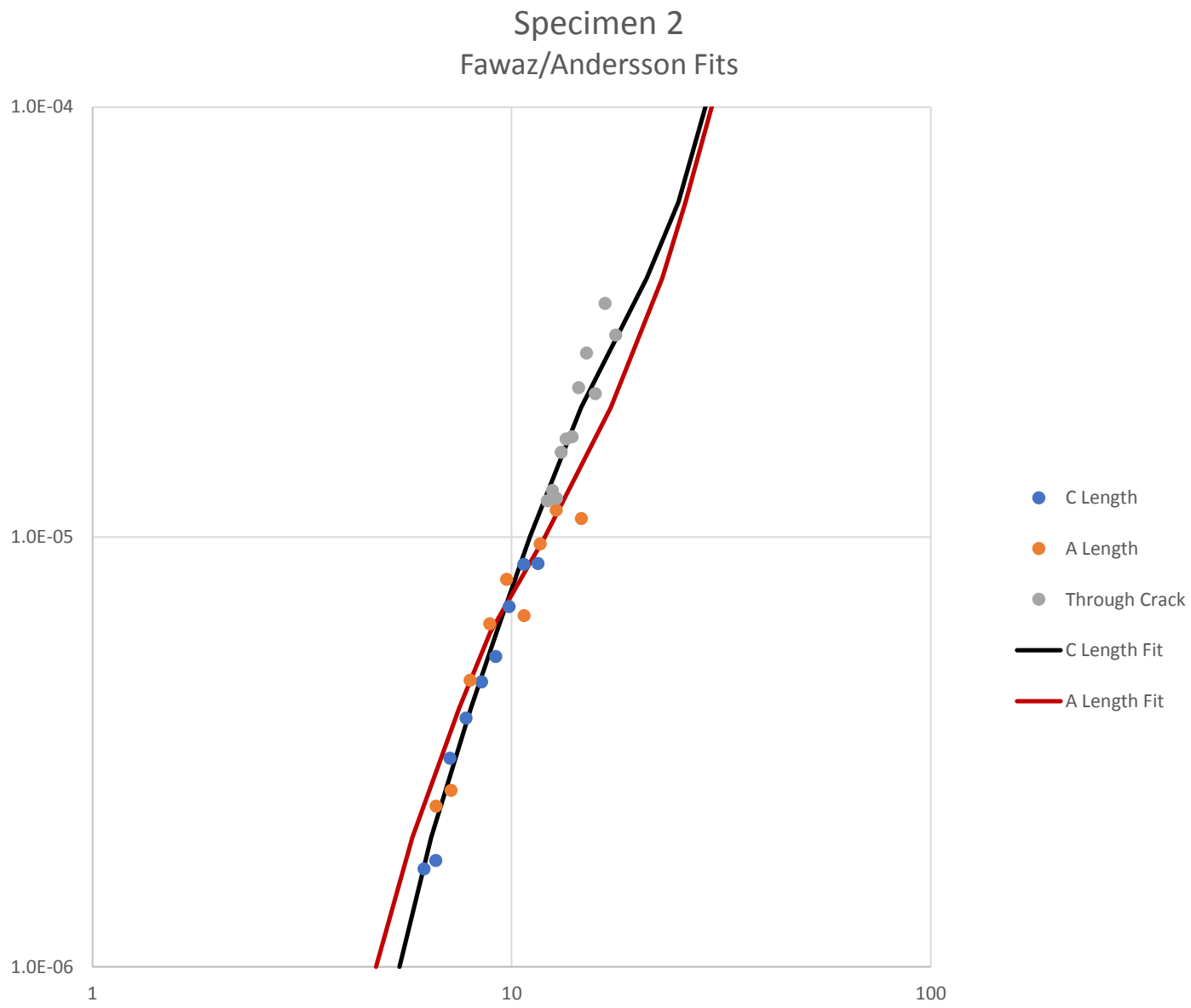

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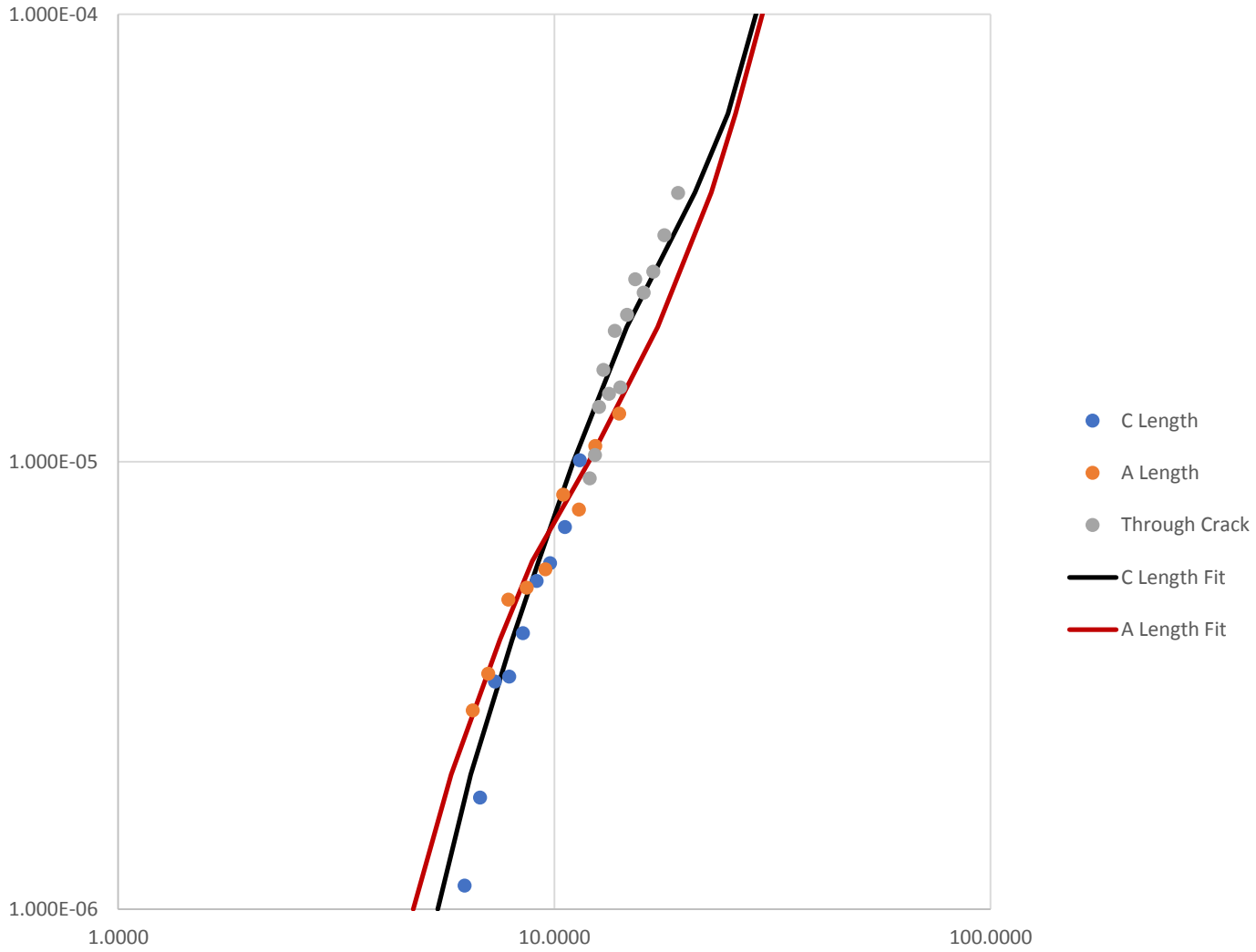
Specimen 3

Fawaz/Andersson Fits



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AFGROW Dual Rate Curve Demonstration

Postdictions

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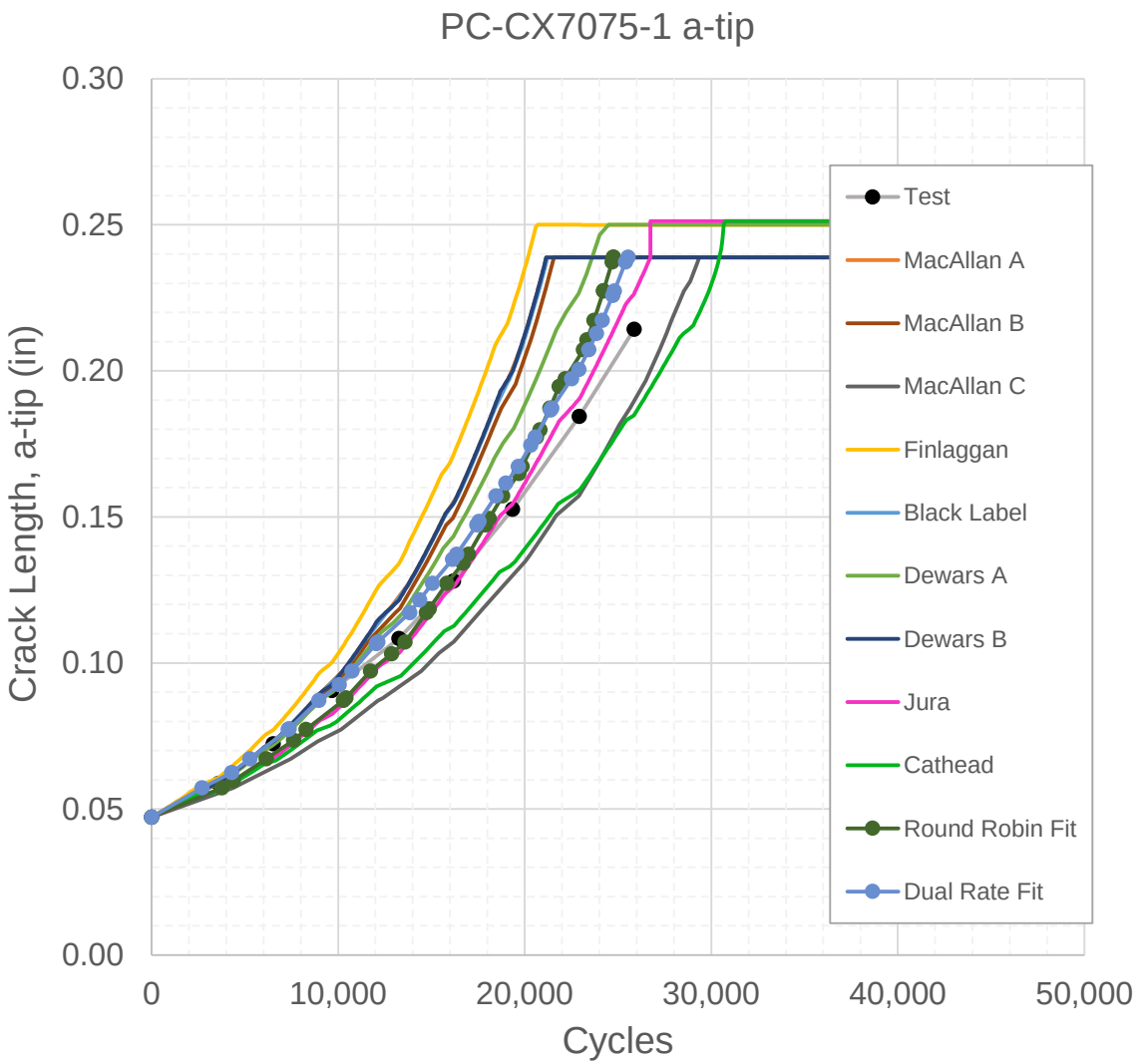

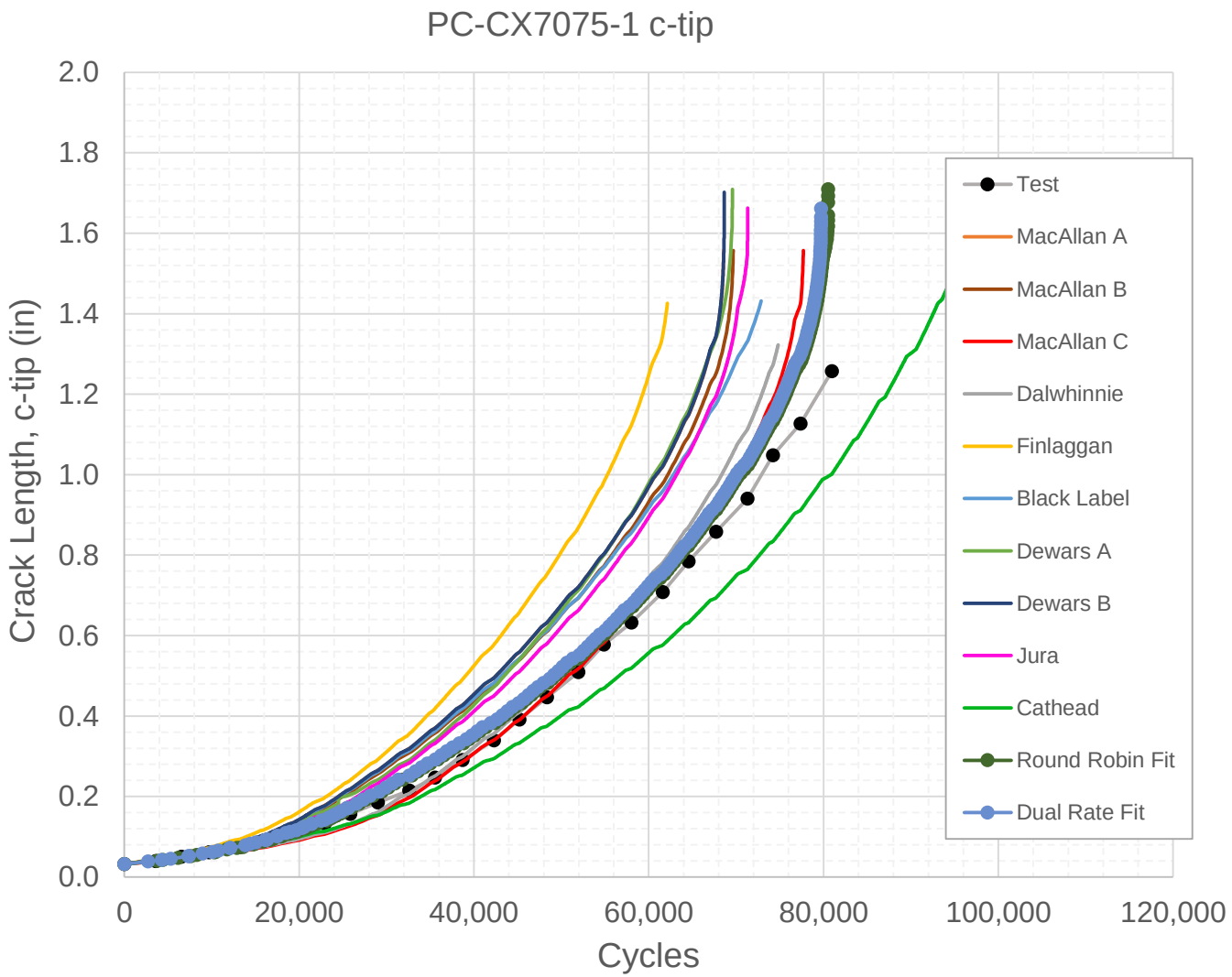

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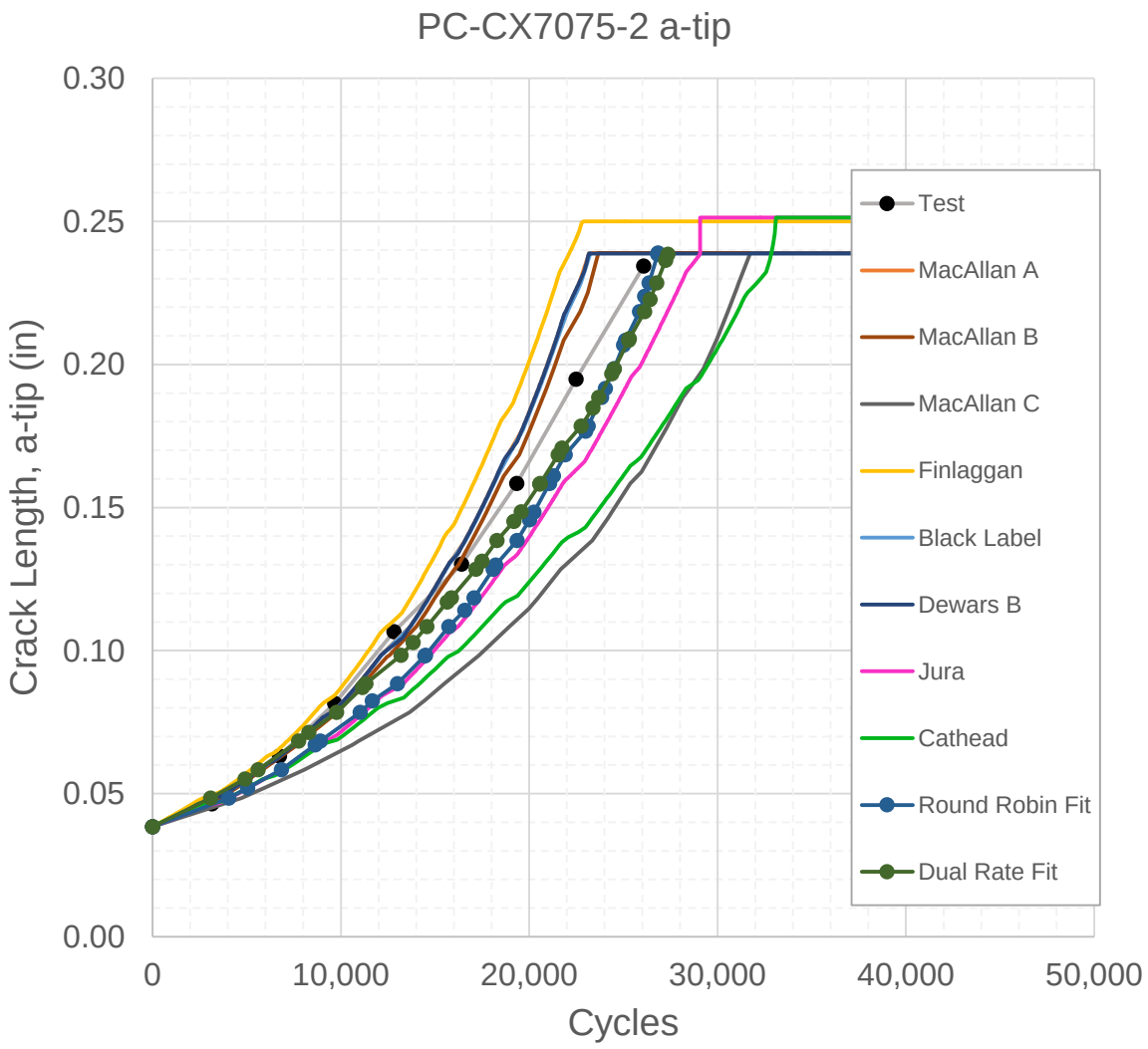

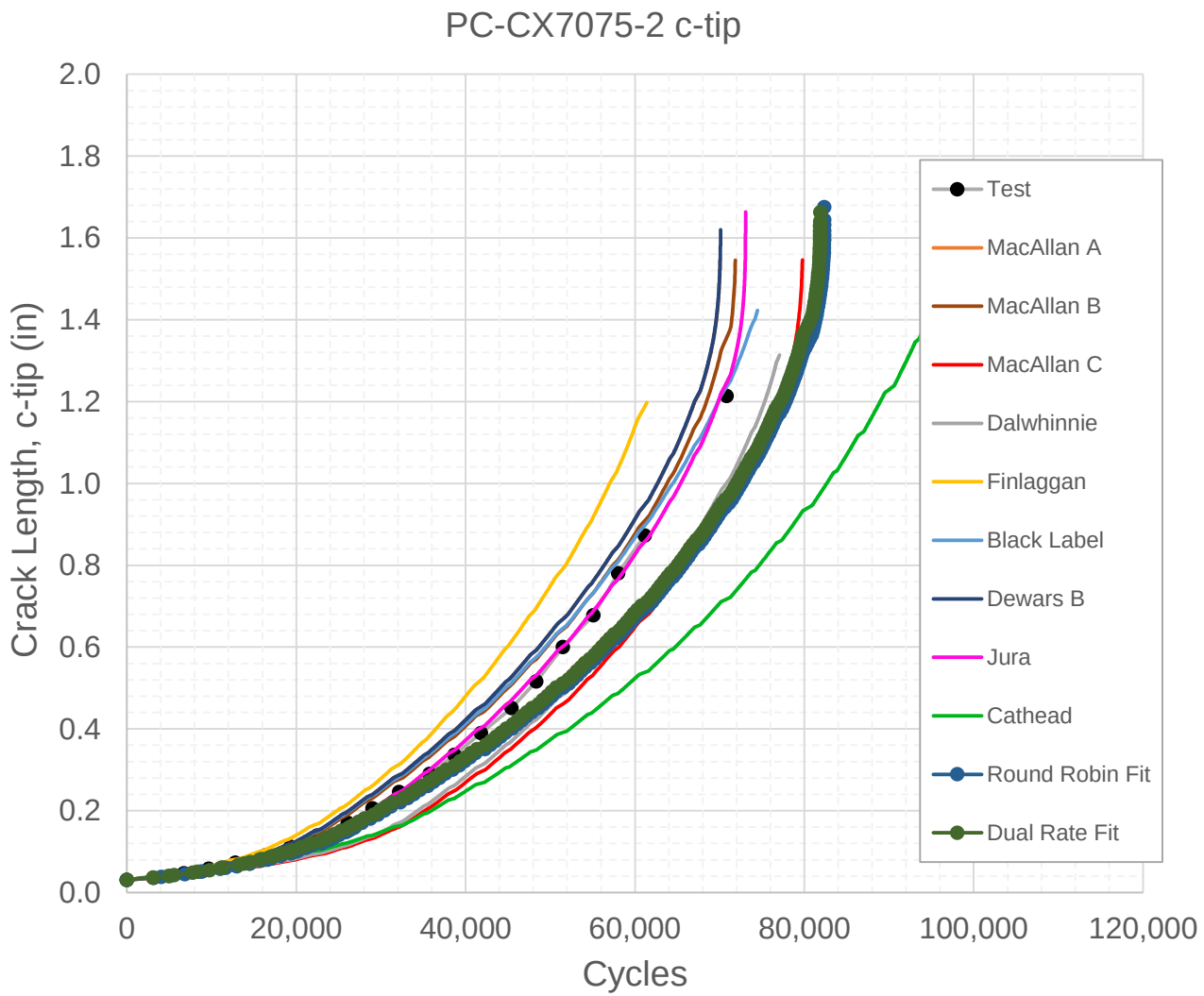

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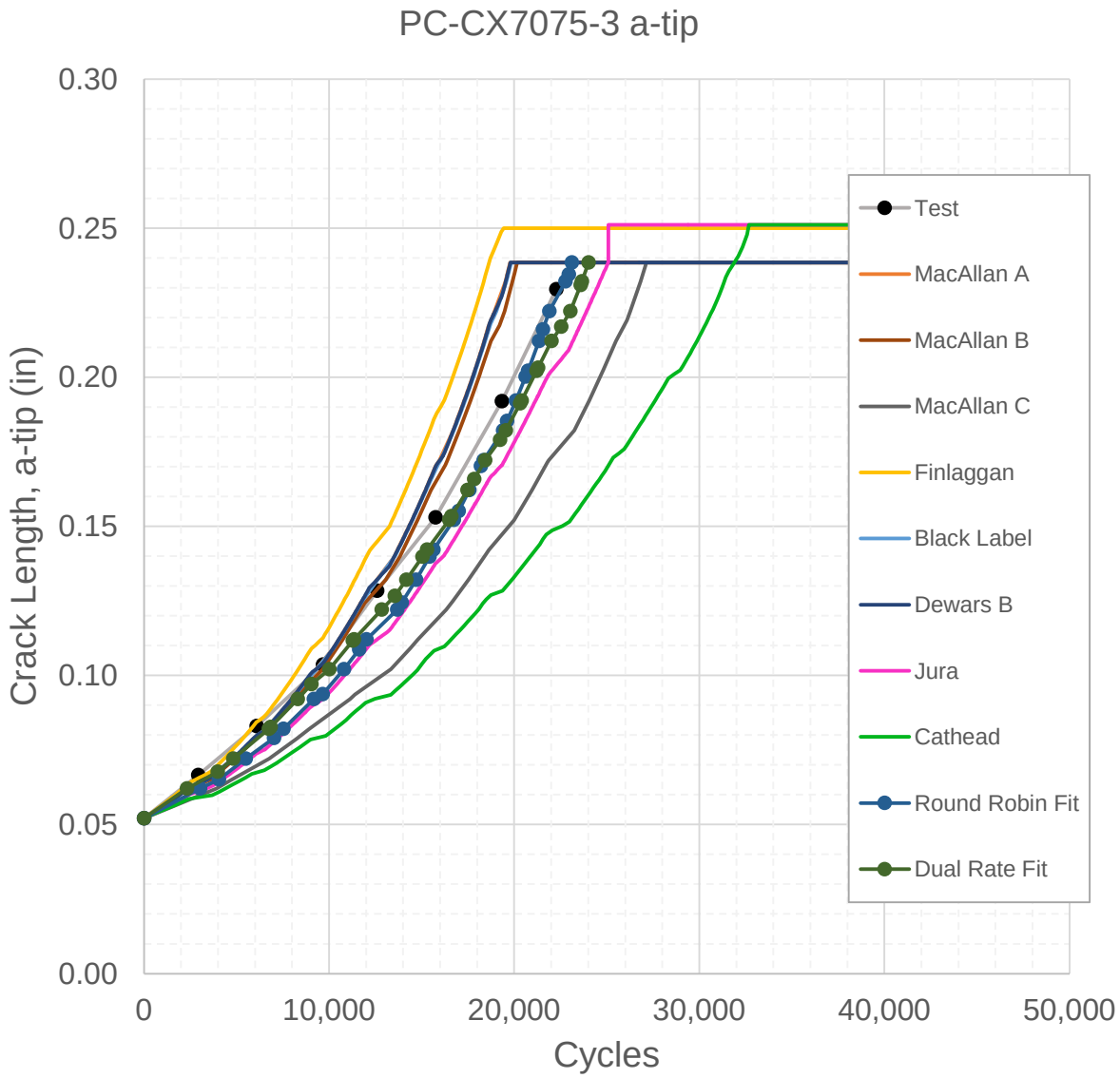

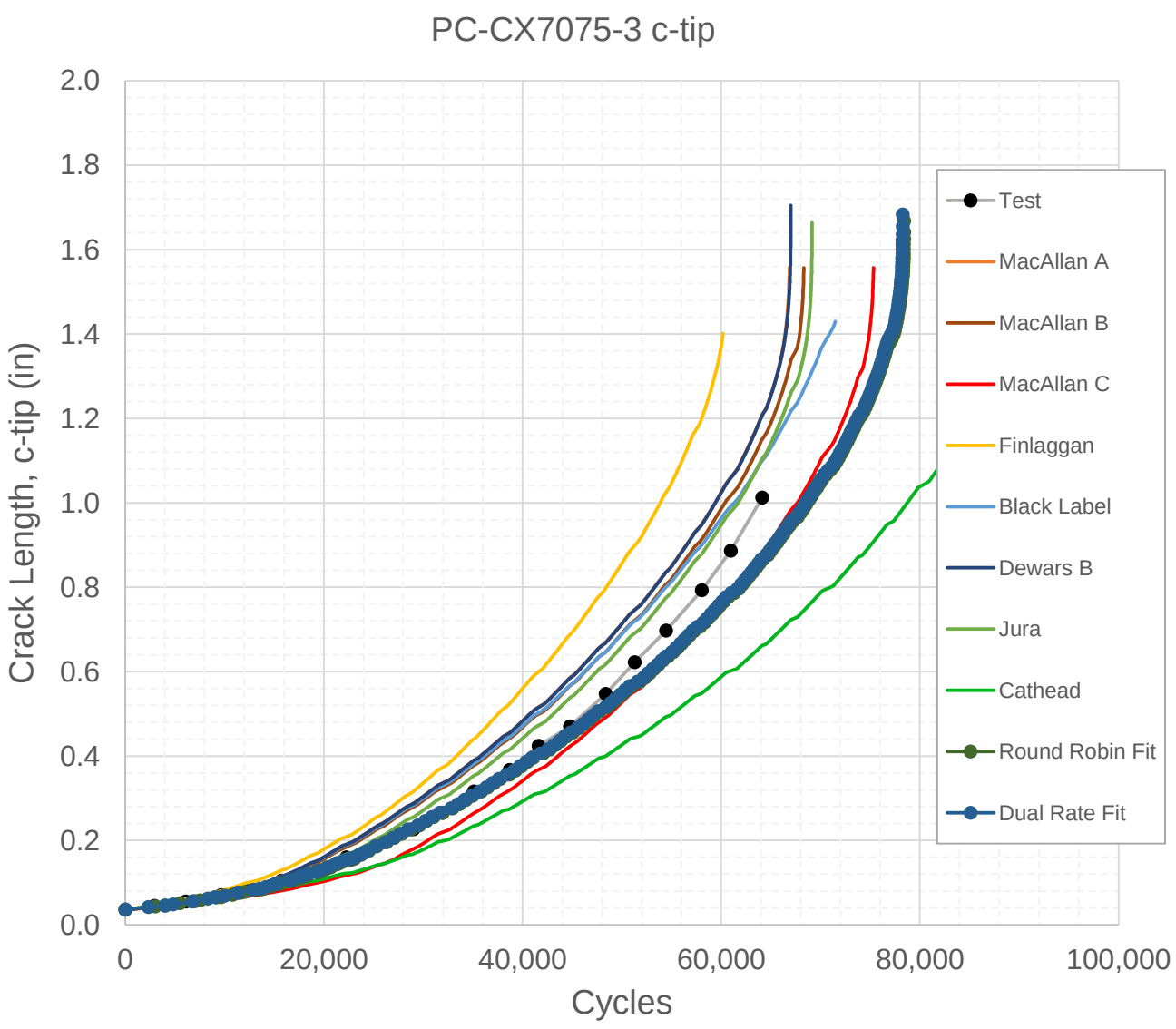

Crack Shape Postdictions

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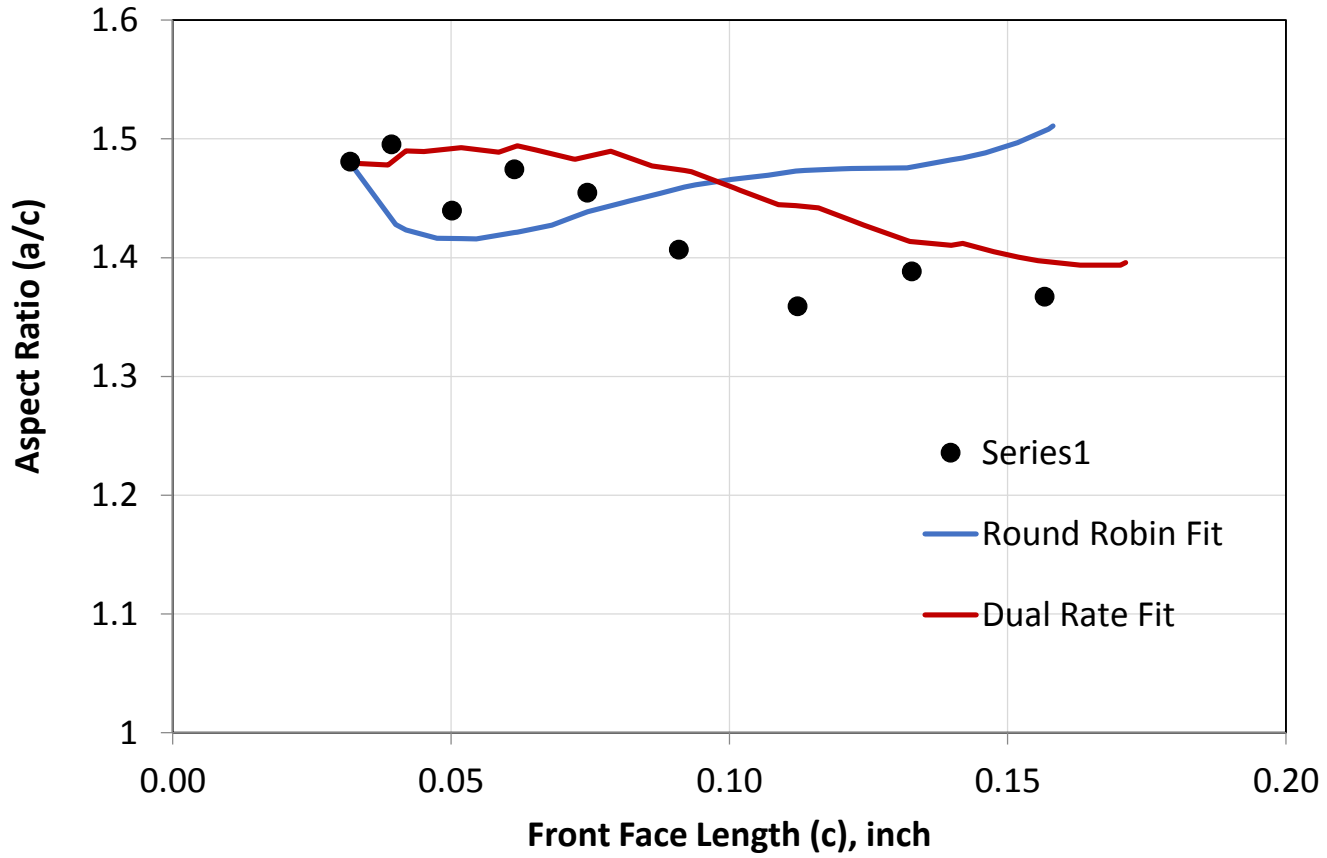
Specimen 1



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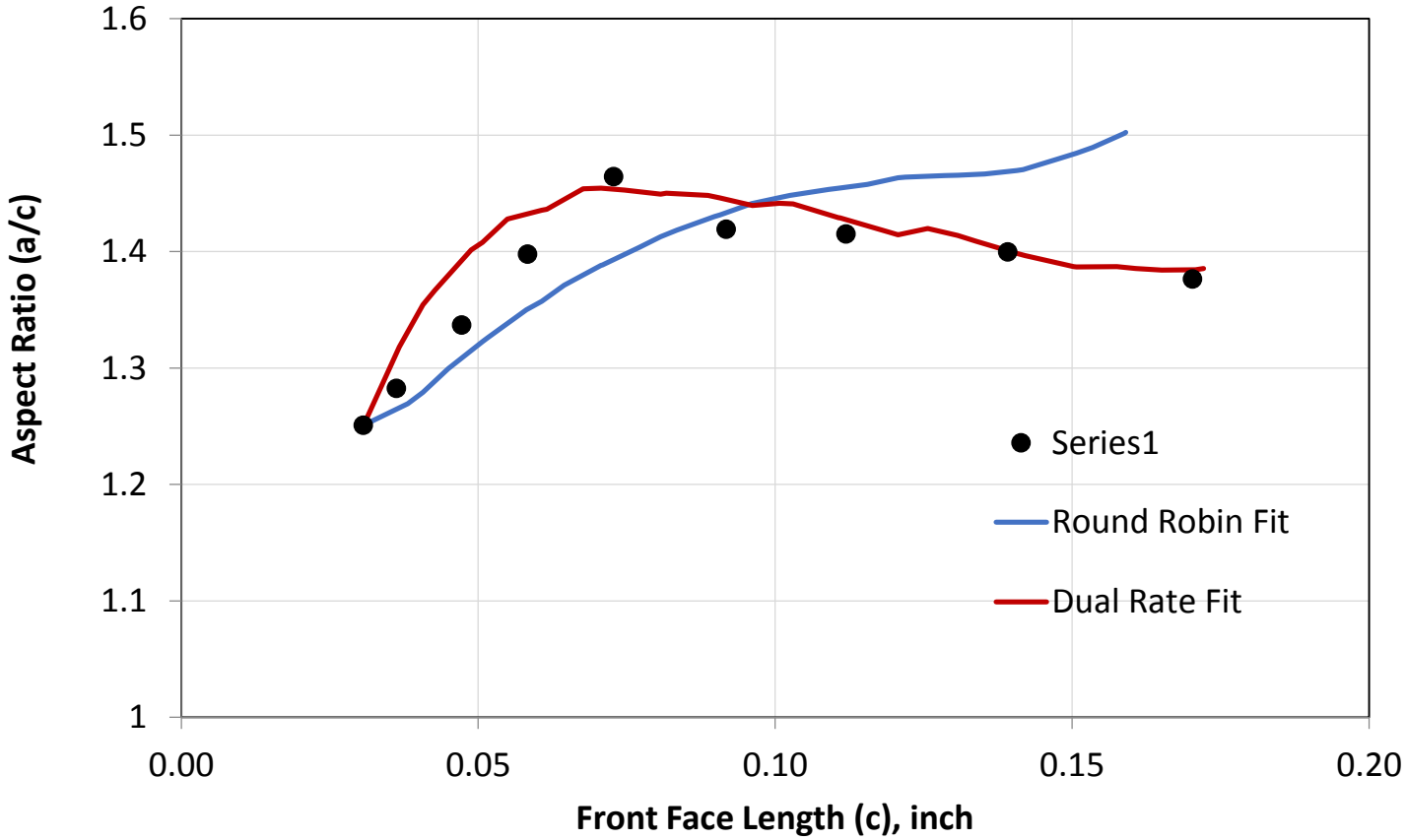
Specimen 2



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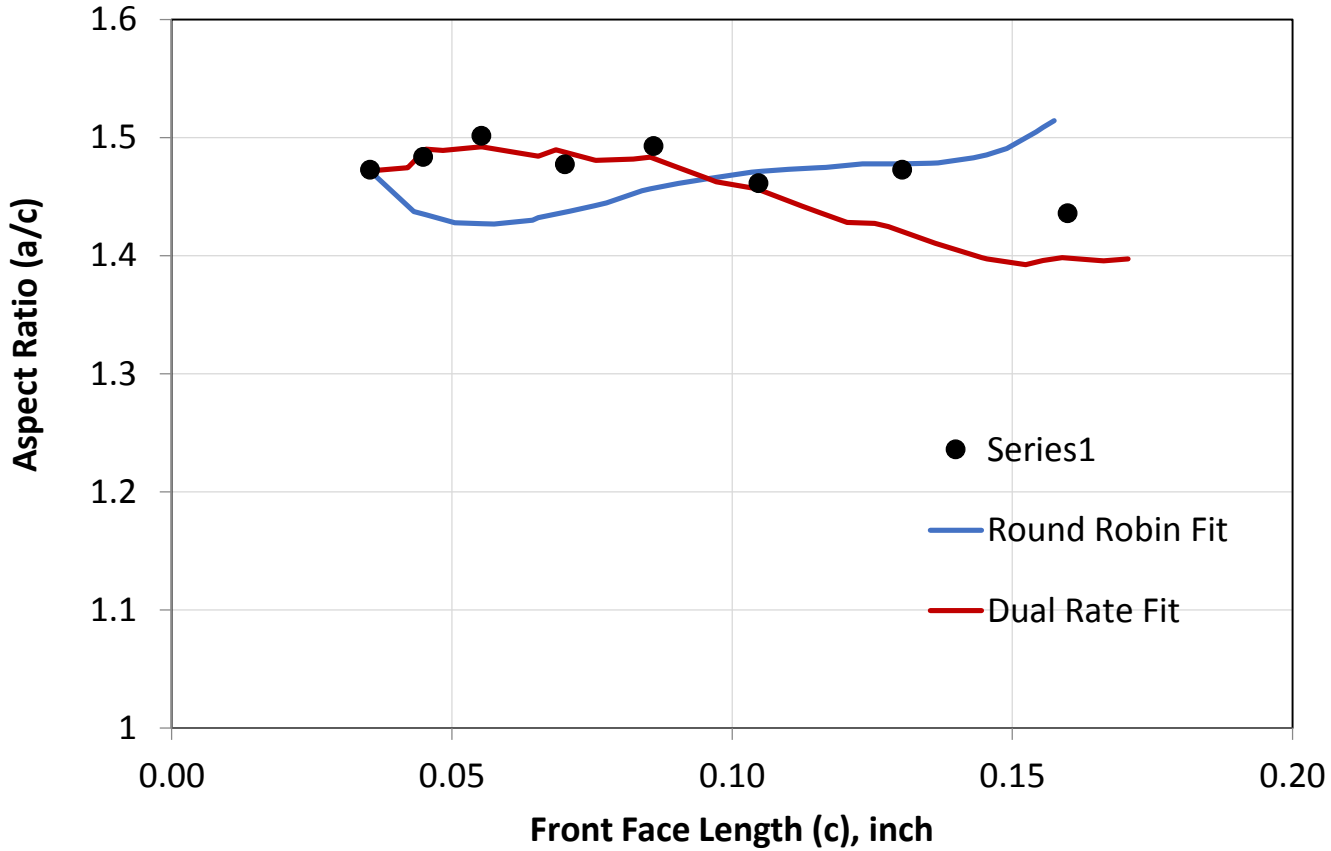
Specimen 3



The Crack Shape Predictions Look Much Better Using Dual Crack Growth Rate Data, But the Life Predictions Are Nearly the Same

Question ?

What happens if you assume a constant crack shape?

(e.g. a/c = 1)

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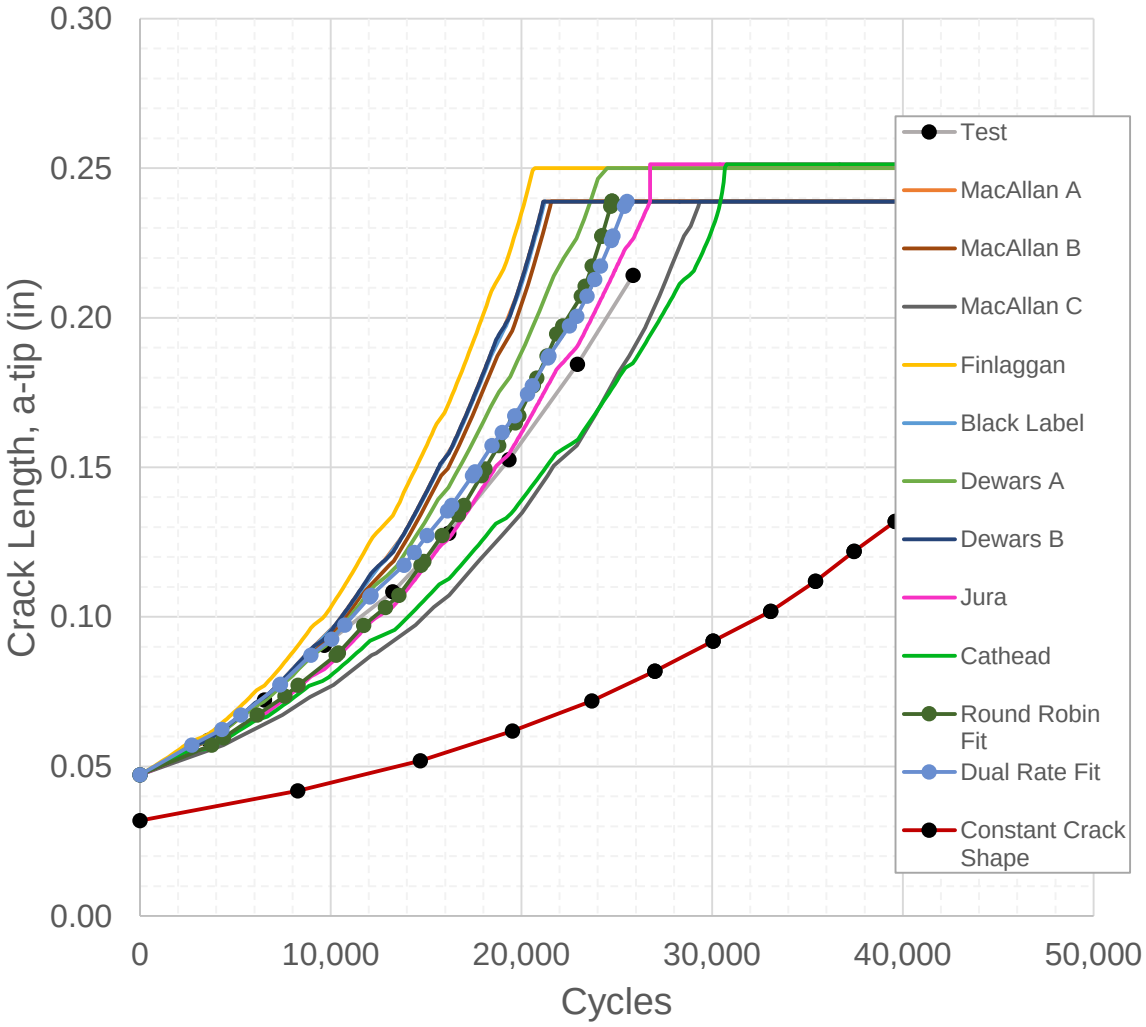
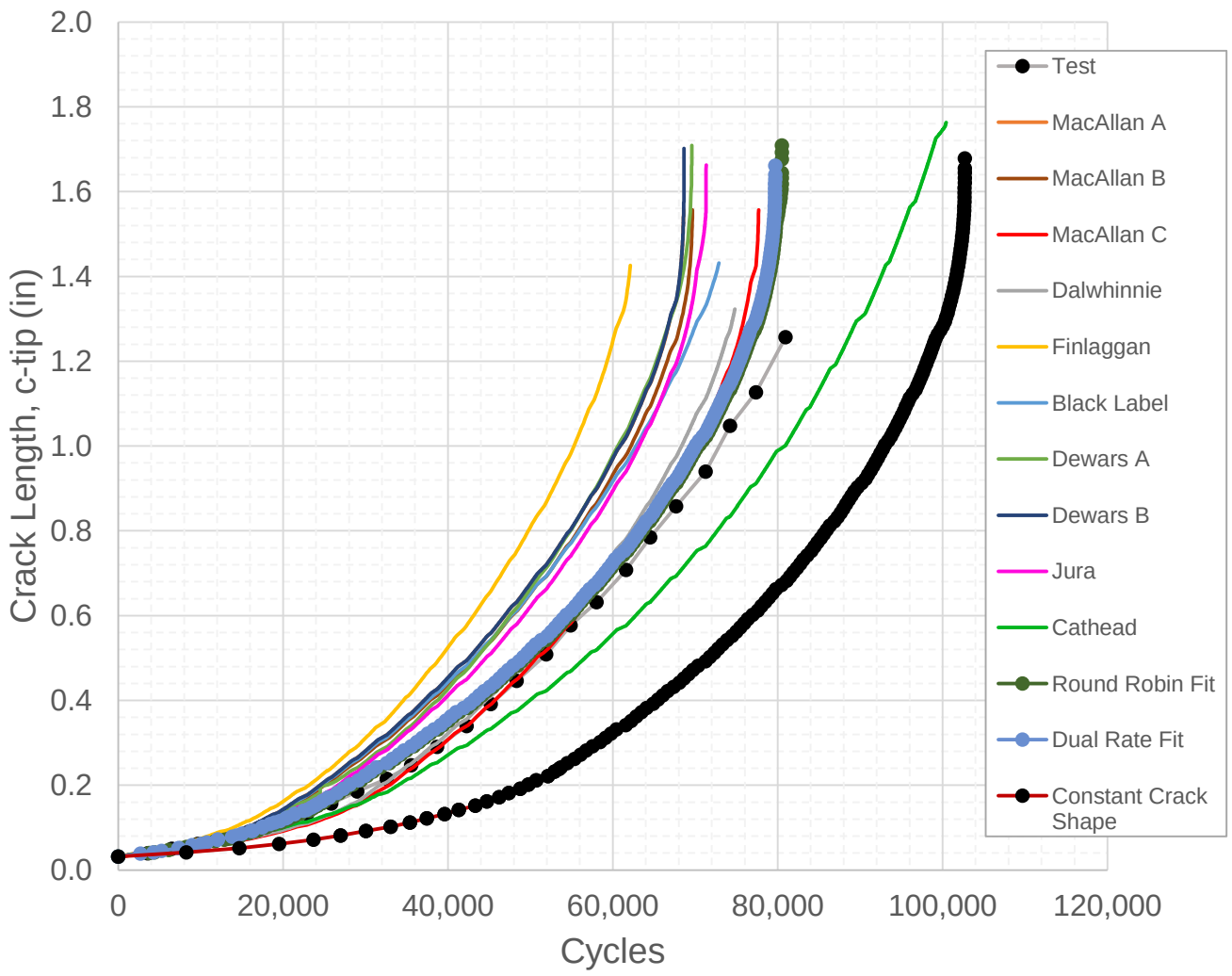
PC-CX7075-1 a-tip



PC-CX7075-1 c-tip



Summary

Life predictions and postdictions are in good agreement with the test results.

Crack shape trends shown in this effort could not be predicted using a single crack growth rate curve.

Dual crack growth rate models were required to more accurately match the crack shape data.

Additional work is needed to assess the value of using dual (or multiple) crack growth rate curves.

More crack growth rate data are needed to model crack growth in multiple directions.

An interpolation method will be needed to model crack growth rate for multiple points along a crack front.

Crack shape changes can significantly impact life prediction capability for many practical problems (high stress gradients, cold-worked holes, etc.).

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Final Point

Do we expect crack growth rate data to be the same for different grain orientations?

Probably not …

It may be time to consider a new approach.

Questions/Comments?