ERSI Round Robin Corner Crack and Thru Crack Data Comparisons

Jake Warner

Overview

- **Discussion of round robin analyses led to questions about whether analyses are more consistent/accurate for thru cracks vs corner cracks or the transition between the two or a combination**

- **Analysis and test results were separated into separate plots for corner and thru thickness cracks for comparison**

- **Some plots that were included in original round robin results were included here for evaluation and discussion**

Case #1

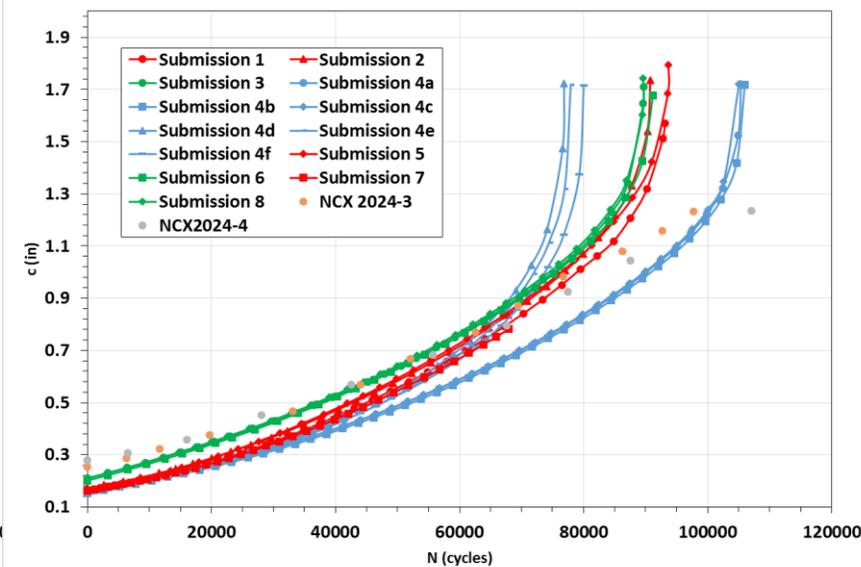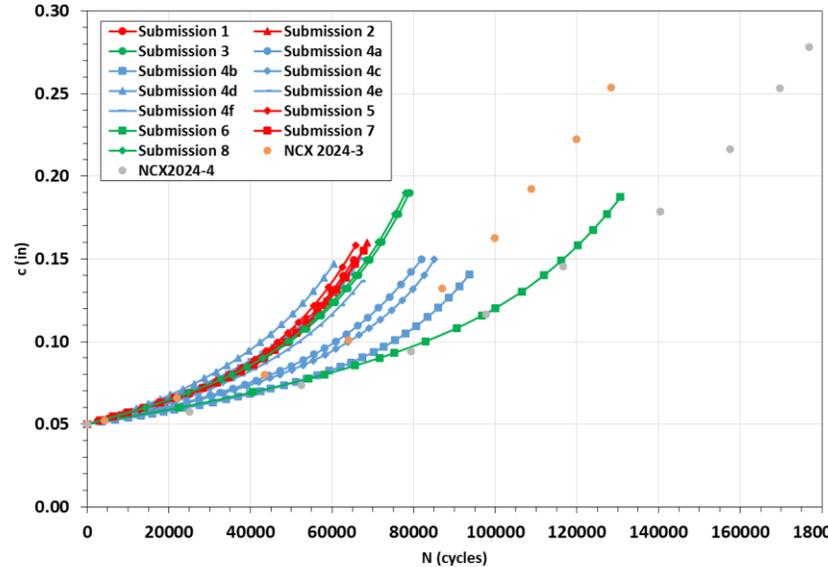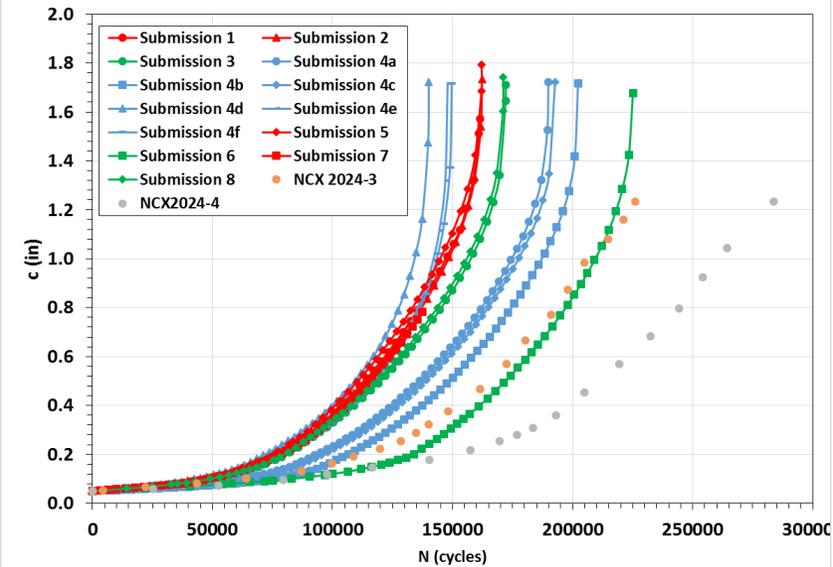## Center Hole

Case #1
Surface Crack ("c")

Full Life

Case #1 - c vs. N

Corner Crack only

Case #1 - c vs. N - Corner Crack Only

Thru Crack only

Case #1 - c vs. N

| Statistics	Average	Range	Std Dev
Test Full Life	266,810	61,105	30,553
Analysis Full Life	170,286	87,639	24,875
Corner Crack Only Test	152,619	48,473	24,237
Corner Crack Only Analysis	81,281	70,710	18,466
Thru Crack Only Test	114,191	12,632	6,316
Thru Crack Only Analysis	89,774	38,035	11,253

- Analysis generally conservative, more so for corner crack
- Smallest standard deviations are for thru crack
- Thru crack is only instance where test std. dev. is smaller for test than analysis
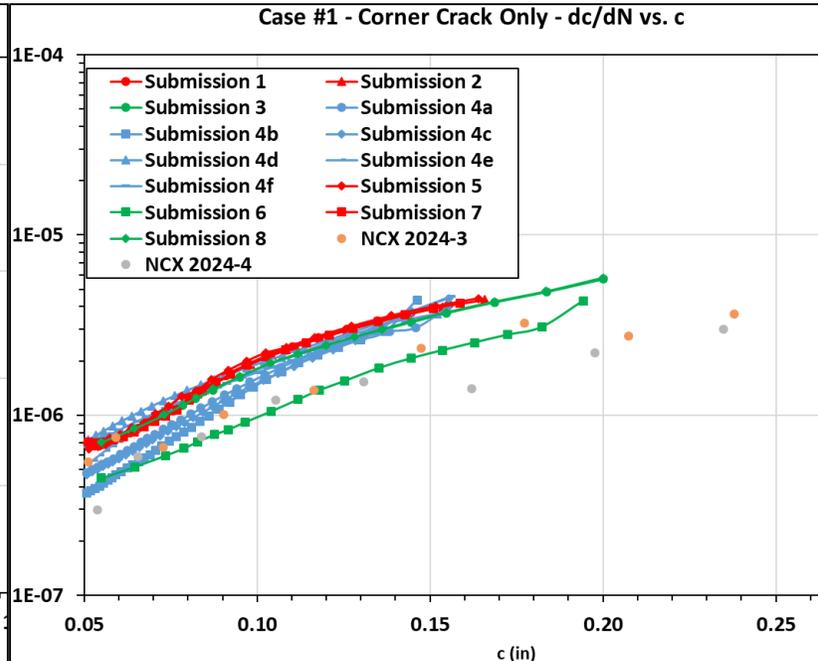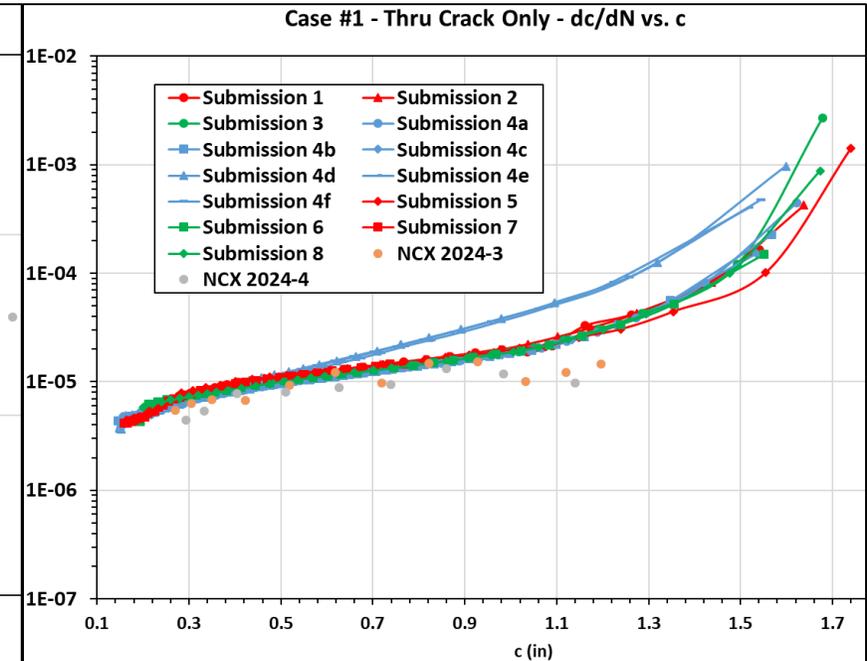
Case #1
dc/dN Comparisons
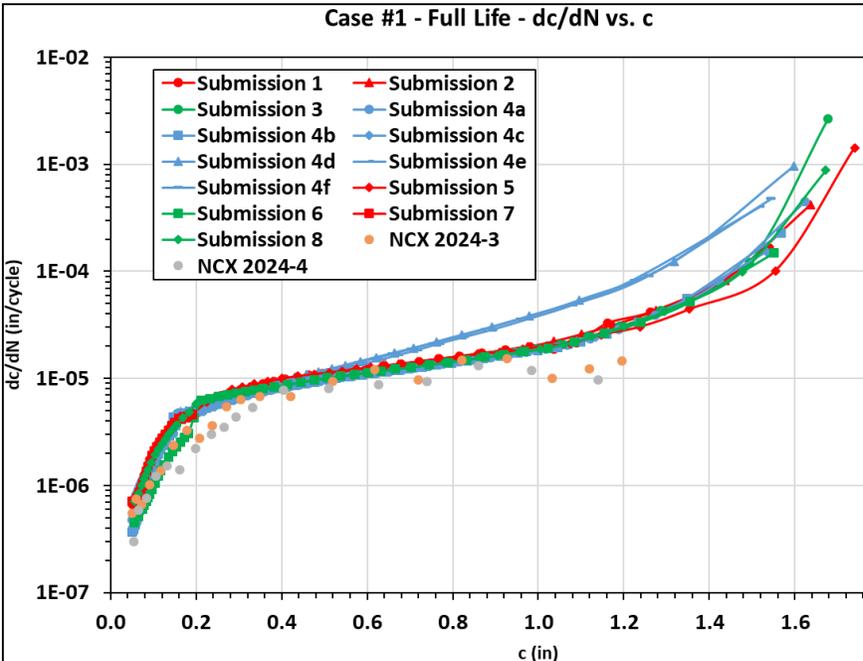
Full Life   Corner Crack only   Thru Crack only

- "knee" around c = 0.2" on full life plot (left) is the transition between corner to thru crack which is why the other two plots are linear
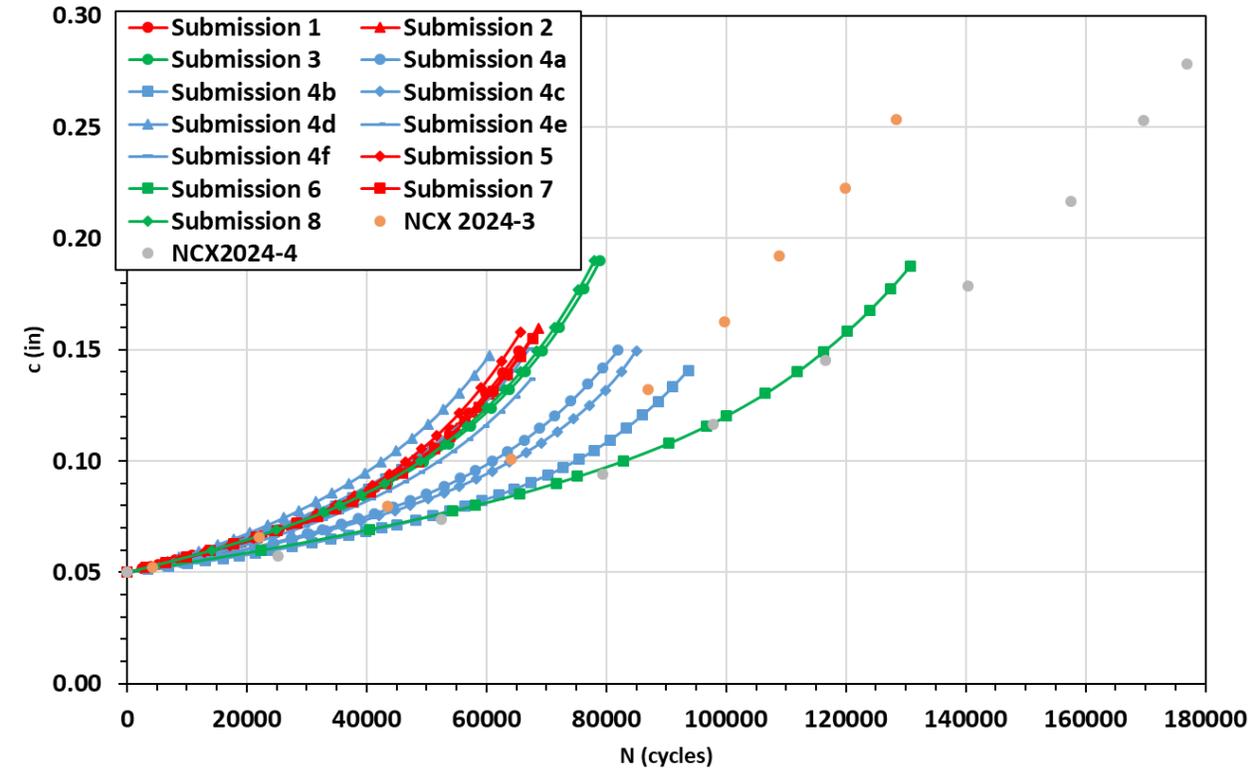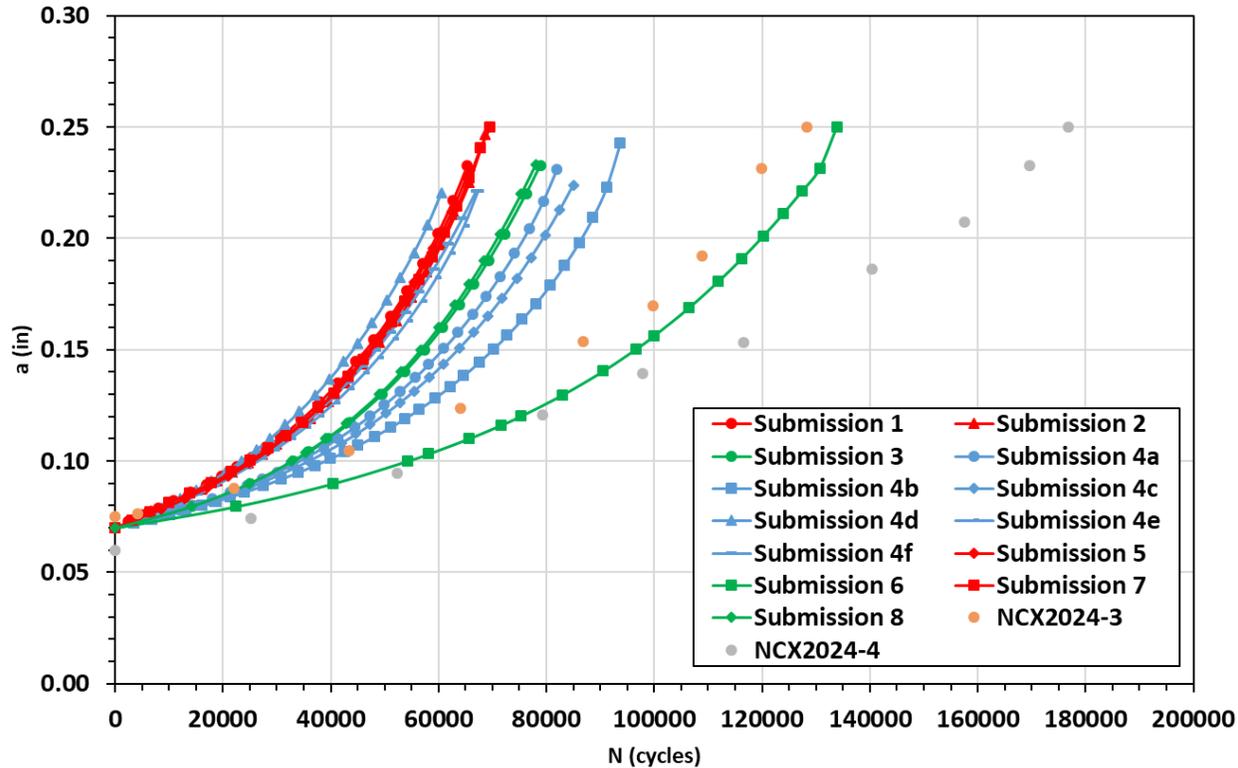
"a" crack (in hole bore)   "c" crack (along surface)
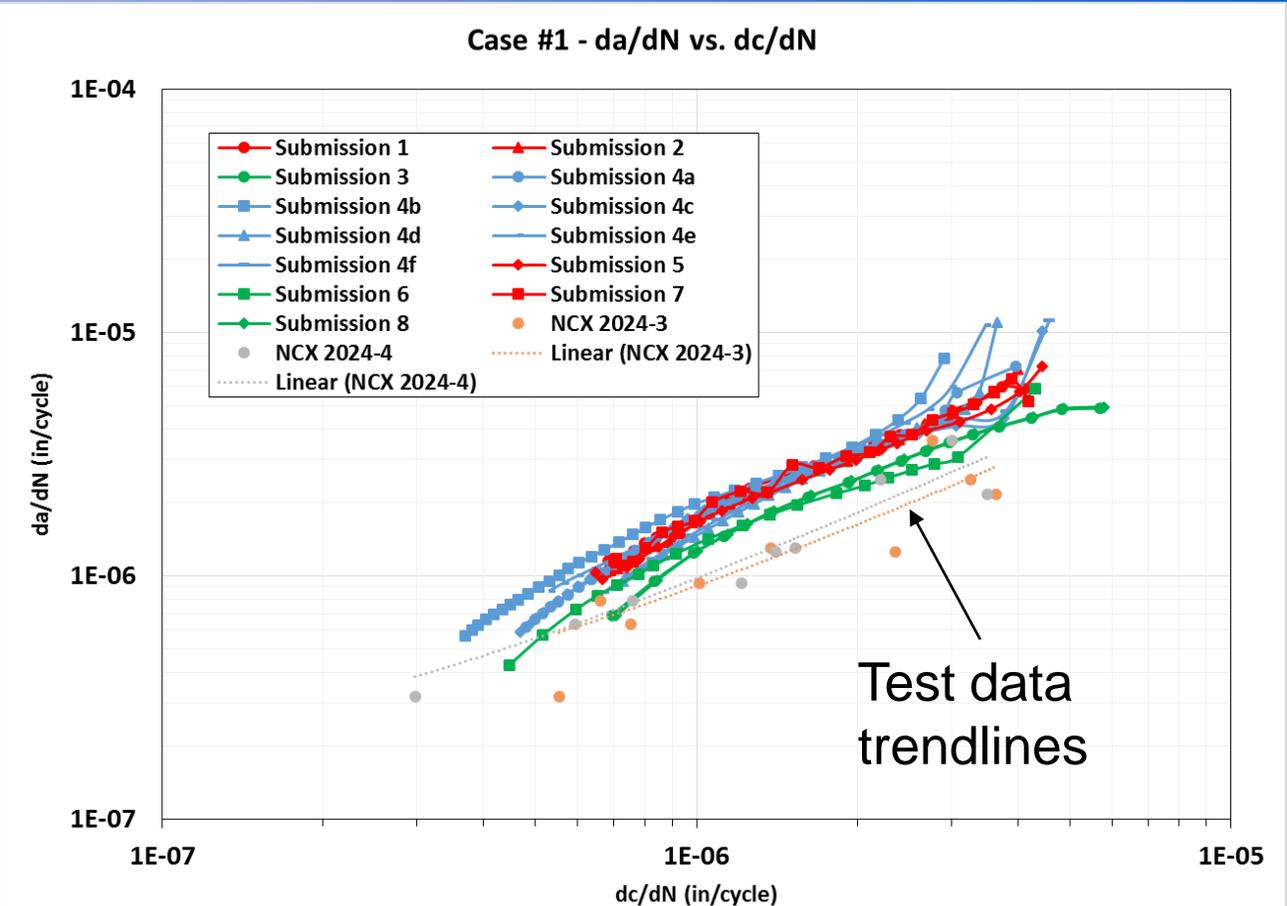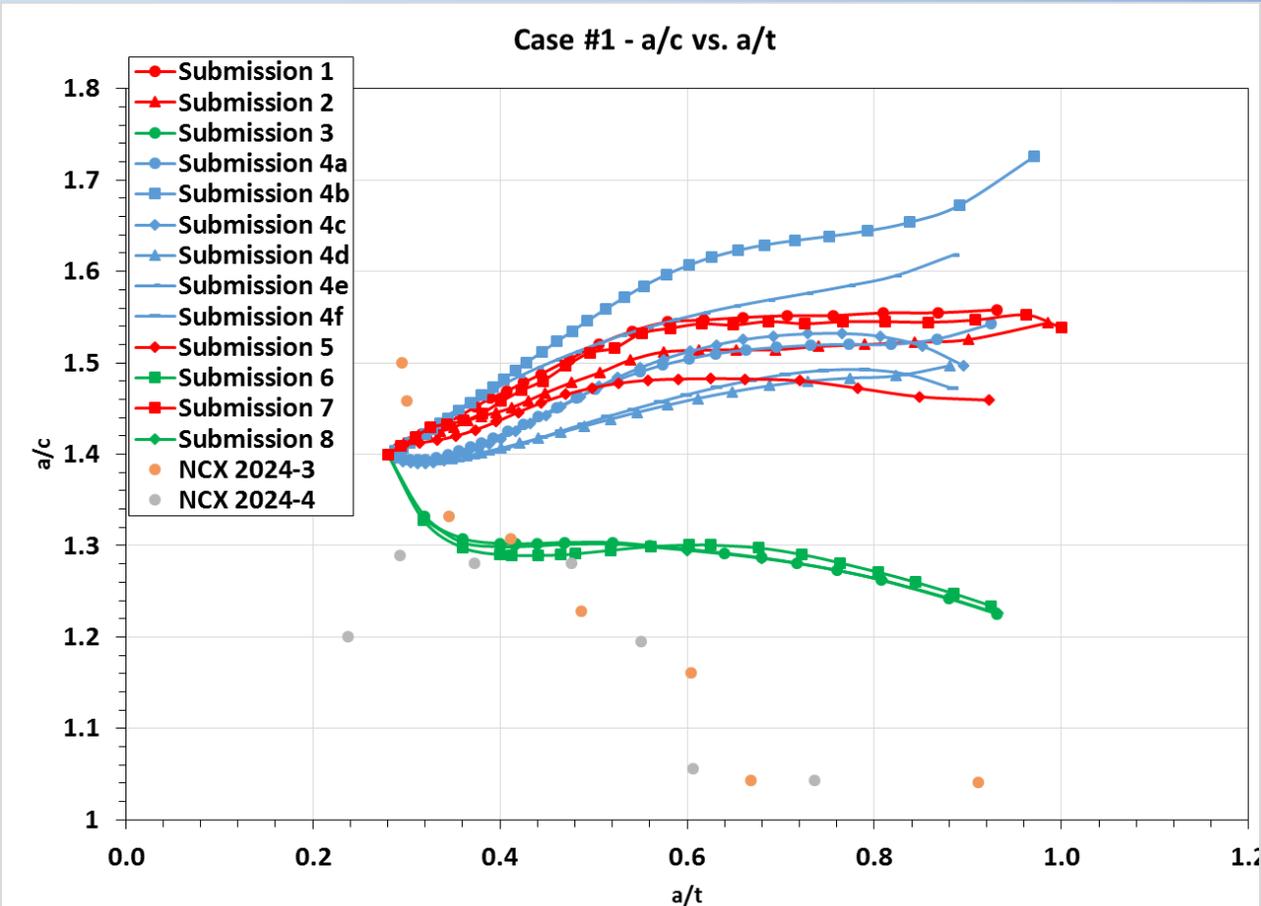

Case #1 - a vs. N

Case #1 - c vs. N - Corner Crack Only

- Test data surface cracks much longer (0.05" - 0.1") than analyses before transitioning to a thru thickness crack

Case #1 - a/c vs. a/t

Case #1 - da/dN vs. dc/dN

Test data trendlines

- As previously observed, there is poor agreement between test and analysis for a/c vs a/t plot. Test data trends down to ~1, while analyses stayed with higher aspect ratios
- Test data roughly matches slope of analysis data on da/dN vs dc/dN plot, but test data is lower
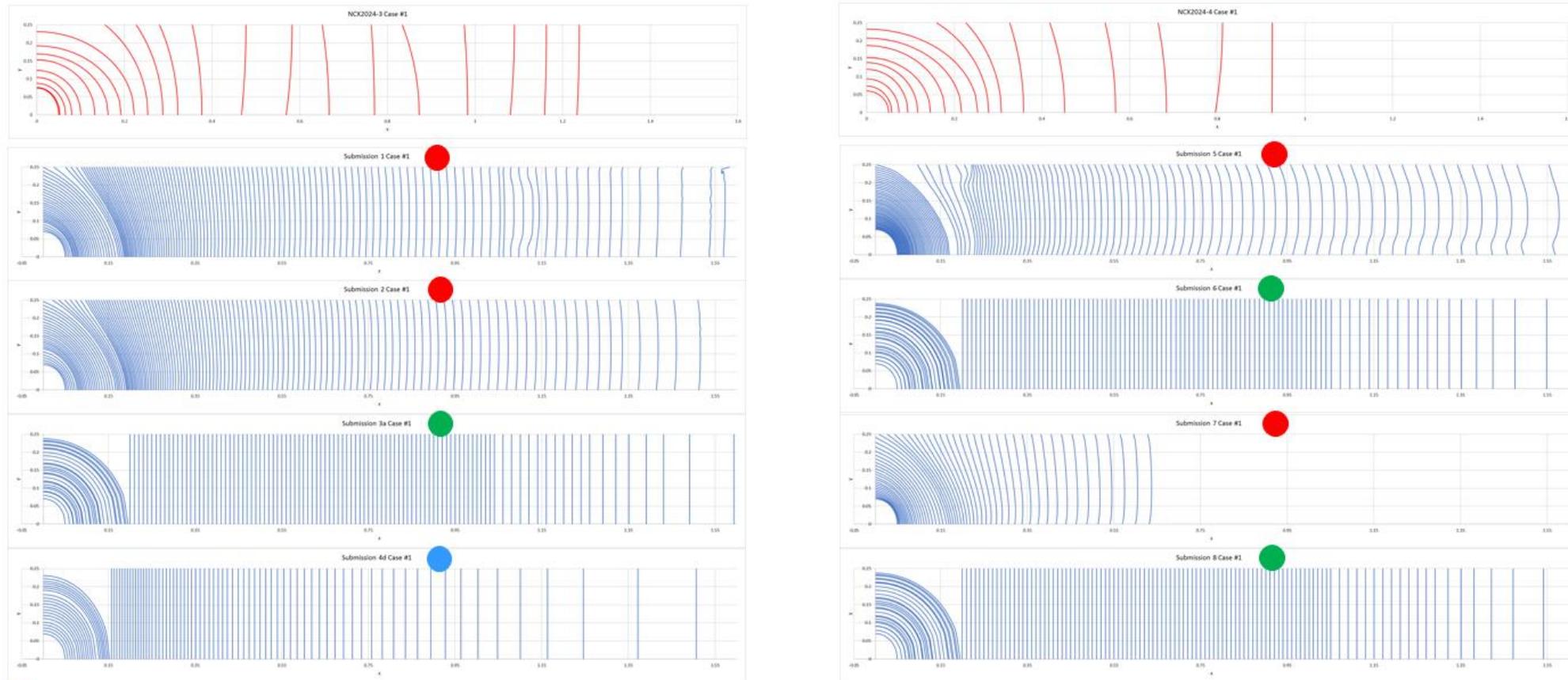
- Test data grew slightly faster along surface during corner crack phase than analyses predicted
- Analyses commonly resemble quarter-circular corner cracks, but test did not

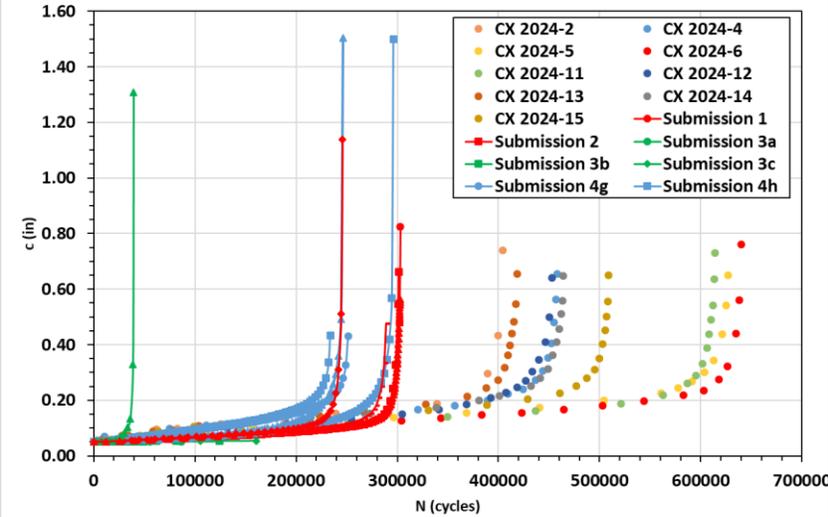Round Robin for Cx Holes – Case #1

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Case #2

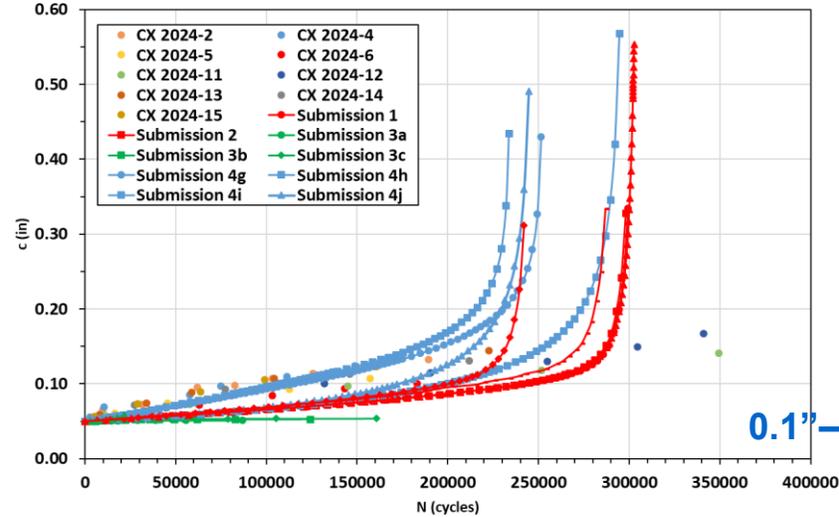## Cold Expanded Center Hole

Case #2
Surface Crack "c"
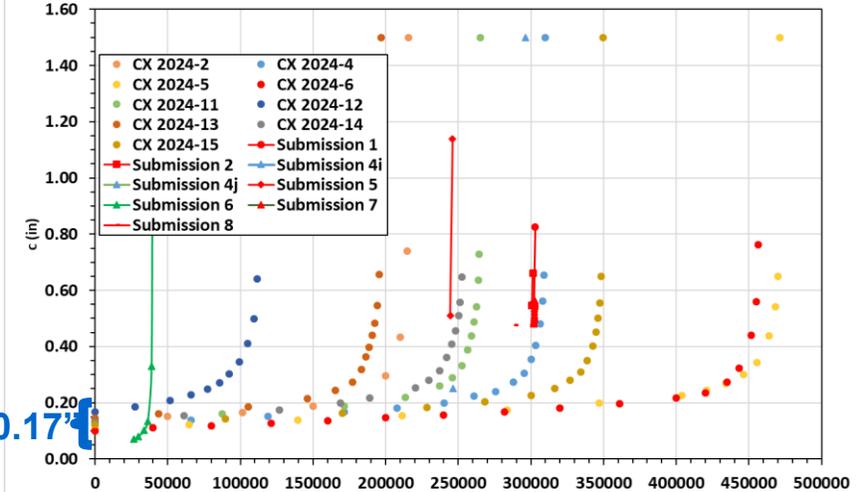
Full Life

Case #2 - Full Life - c vs. N

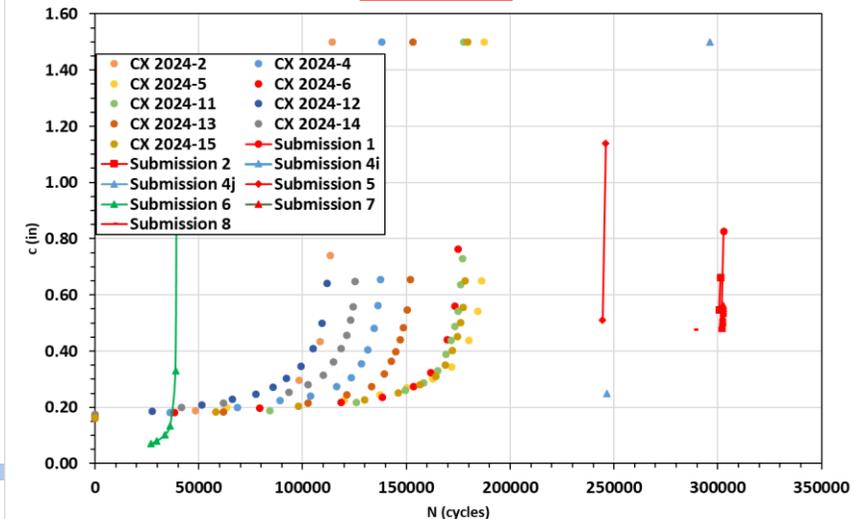### Corner Crack only

Case #2 - Corner Crack Only - c vs. N

Thru Crack only

Case #2 - Thru Crack Only - c vs. N

0.1"–0.17"

Case #2 - c = 0.17 to Failure - c vs. N

- Most analyses predict failure prior to test even becoming thru thickness crack
- Tests were thru thickness over a range of "c" lengths (0.1"-0.17")
- If thru thickness test crack lengths are plotted from c=0.17" to failure, as shown in bottom right, the test time to failure is fairly consistent, although that is only about ¼ of the tests life
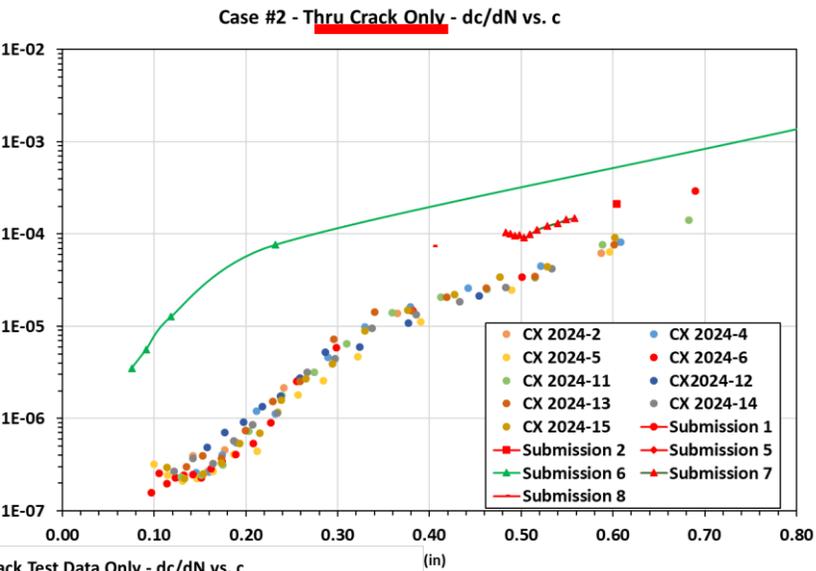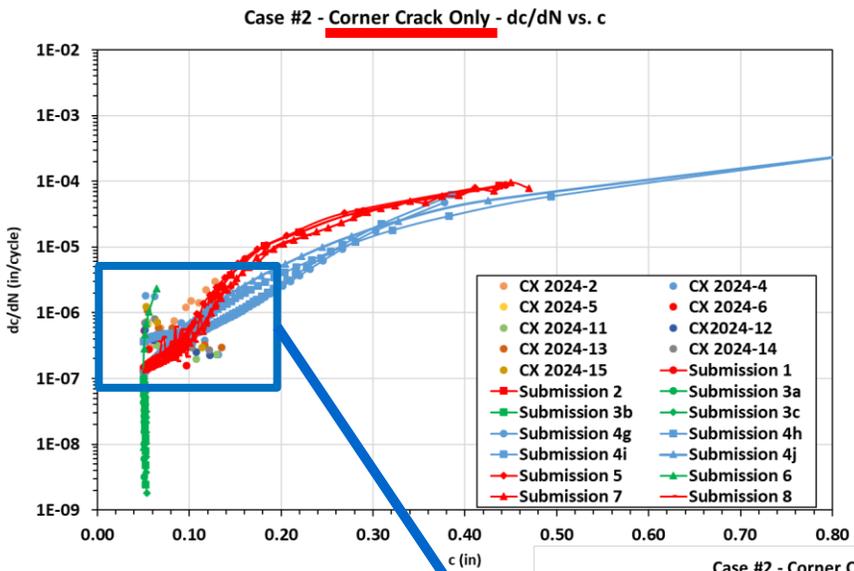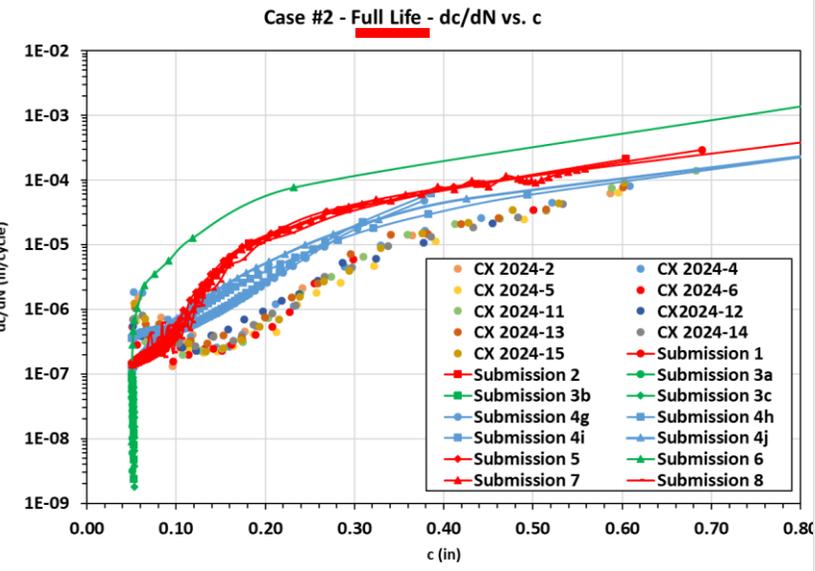
Full Life

Corner Crack only

Thru Crack only

Case #2 - Full Life - dc/dN vs. c

Case #2 - Corner Crack Only - dc/dN vs. c

Case #2 - Thru Crack Only - dc/dN vs. c

Case #2 - Corner Crack Test Data Only - dc/dN vs. c

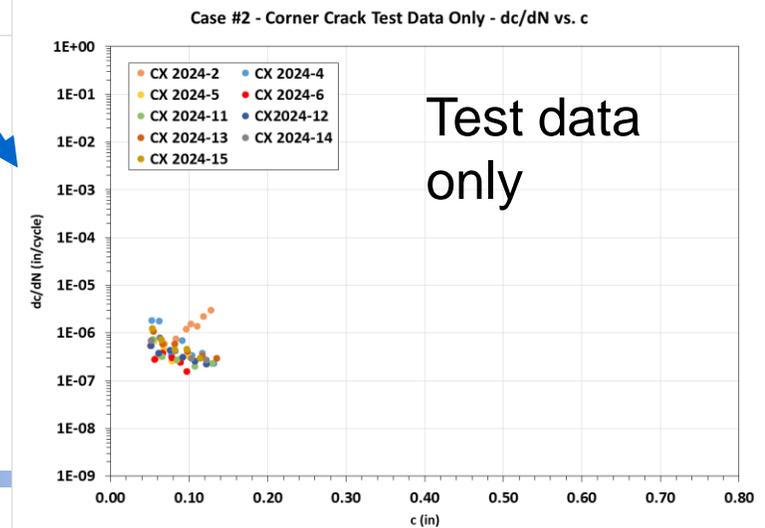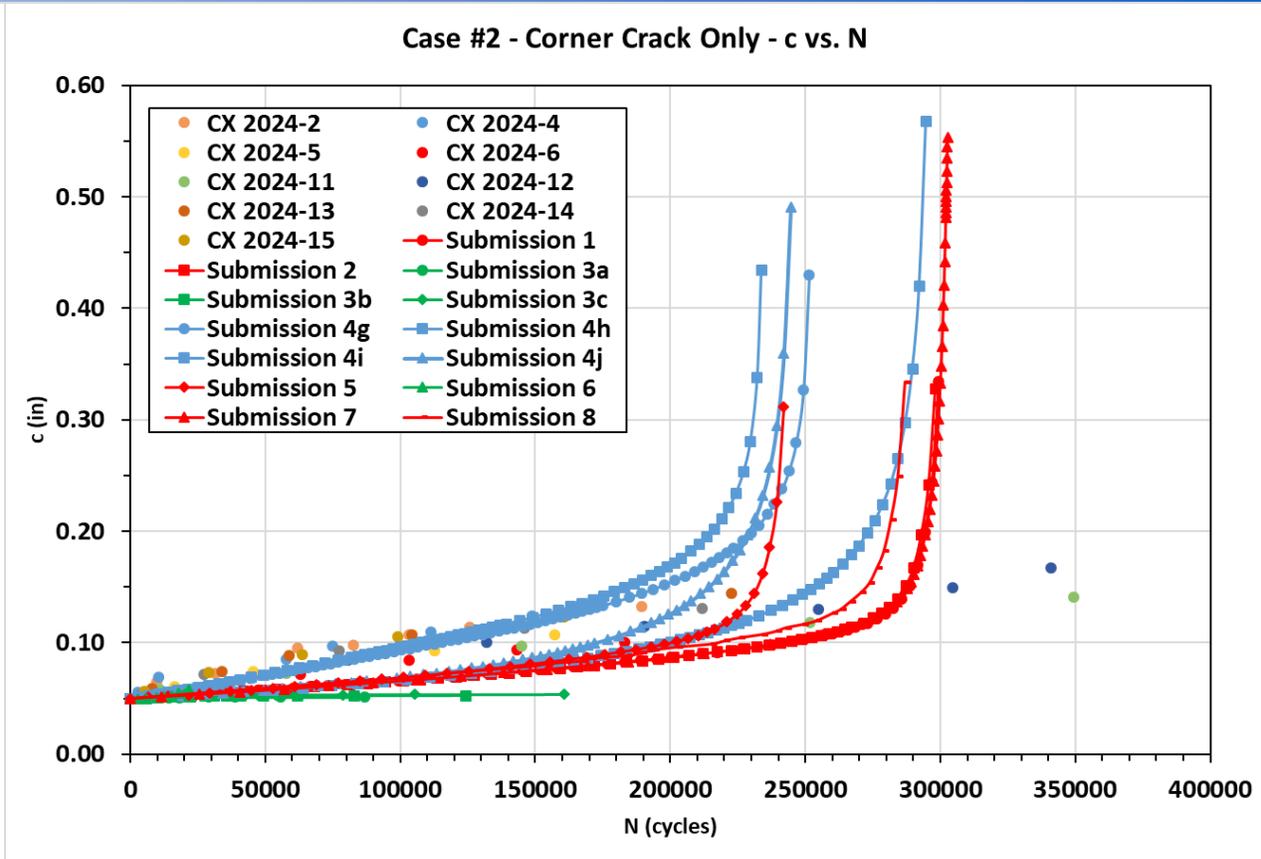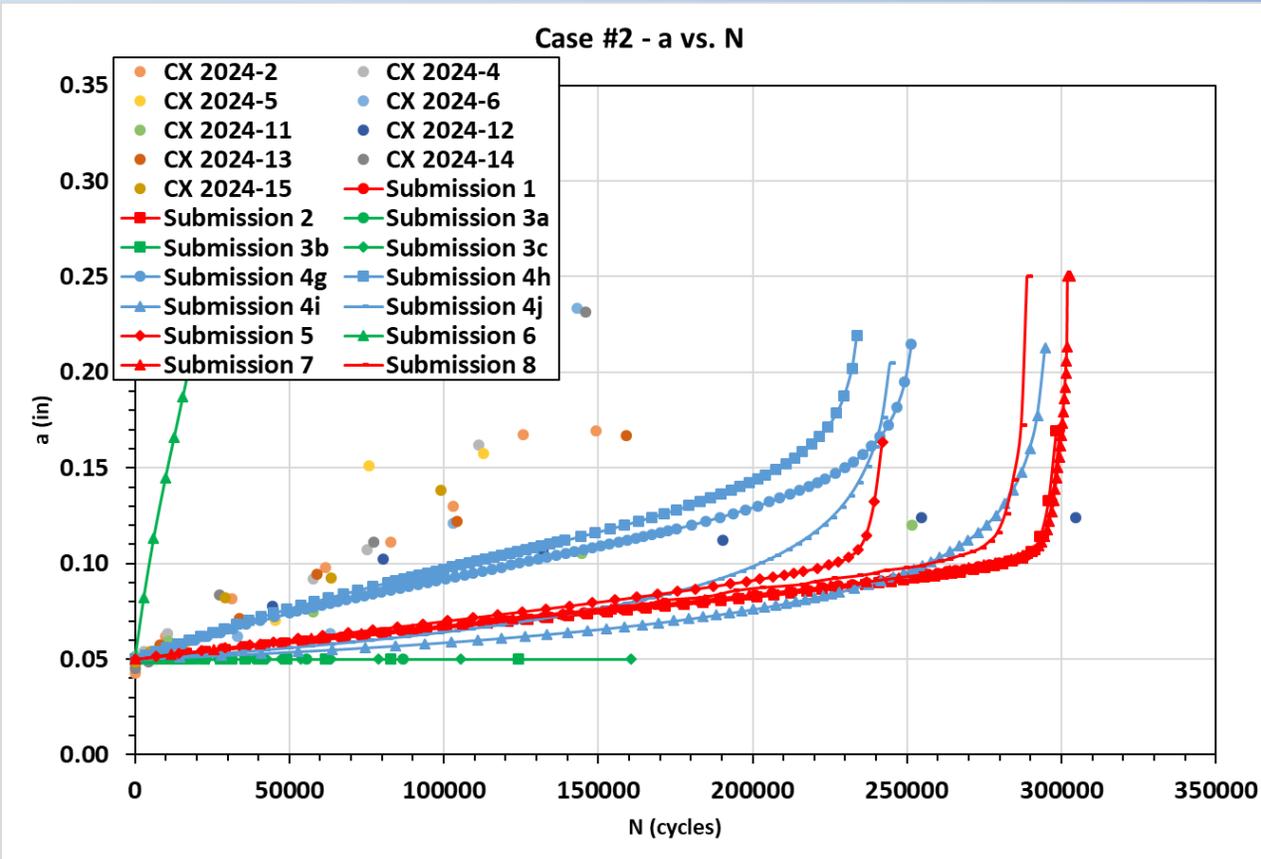Test data only

- In general analyses have higher growth rates than test (top left)
- Analysis corner crack rates cover a broad area of the middle plot, but the test data is tightly grouped as shown in the small plot with analysis data removed

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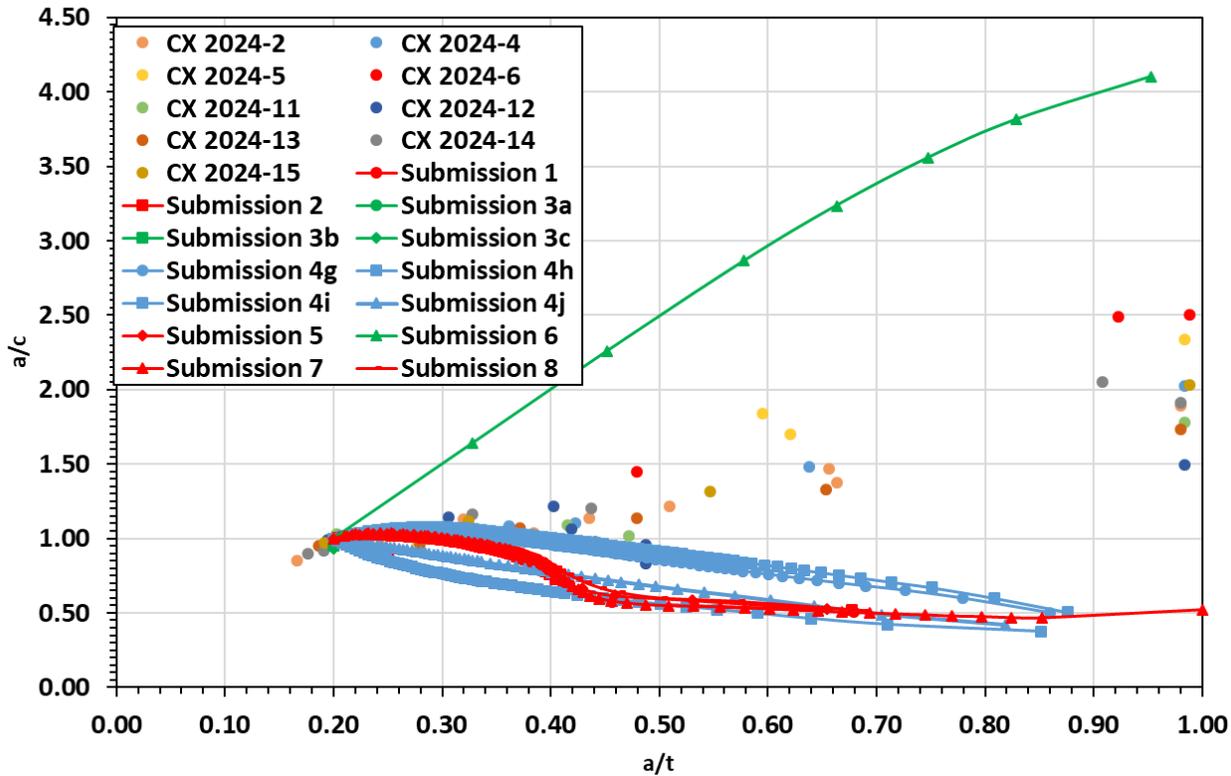Case #2 - a vs. N

Case #2 - Corner Crack Only - c vs. N

- For tests, "a" generally grew much faster than analyses
- Analyses tended to go to unstable crack growth and failure at transition to a thru thickness crack, while test data continued with stable crack growth
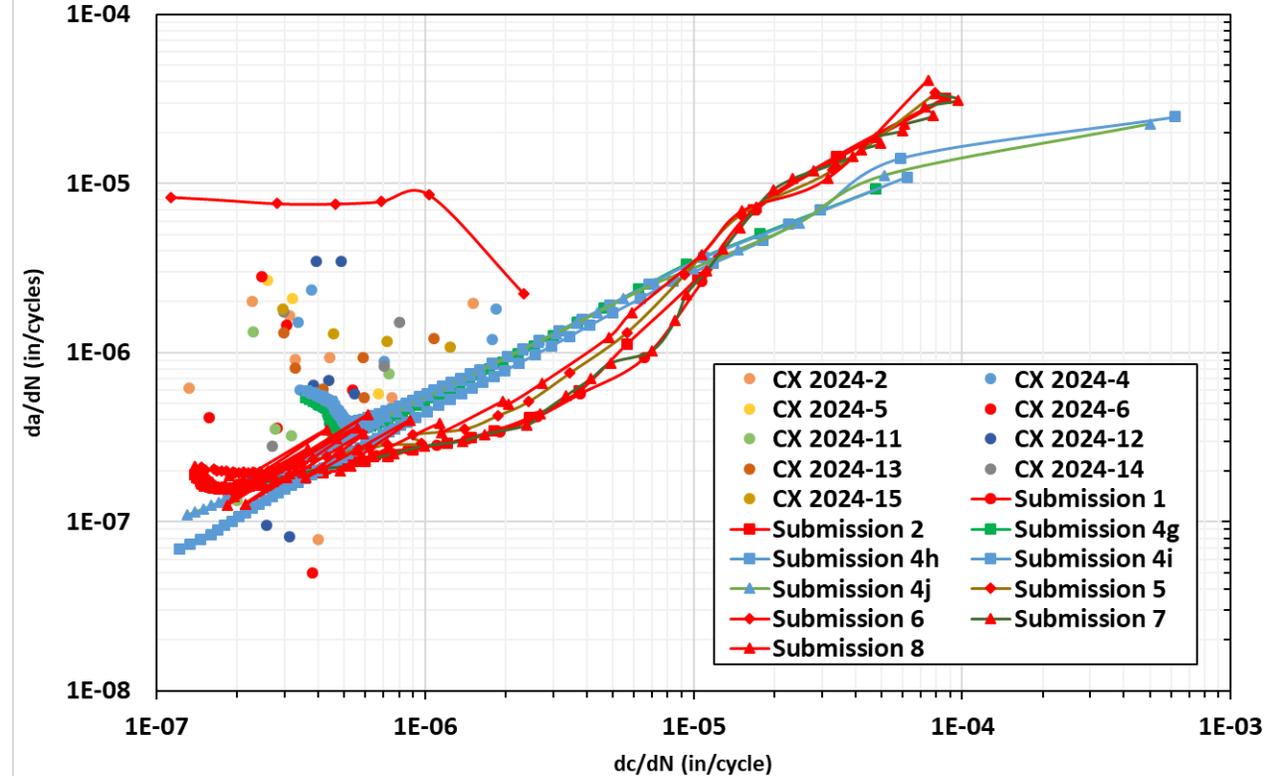
Case #2 - a/c vs. a/t

Case #2 - da/dN vs. dc/dN

- Aspect ratio started near 1, whereas Case #1 (non-CX) a/c started higher, near 1.4
- Slope of test data on aspect ratio is positive, but was negative for Case #1
- For da/dN vs dc/dN plot test data is now above analysis data, also opposite of Case #1
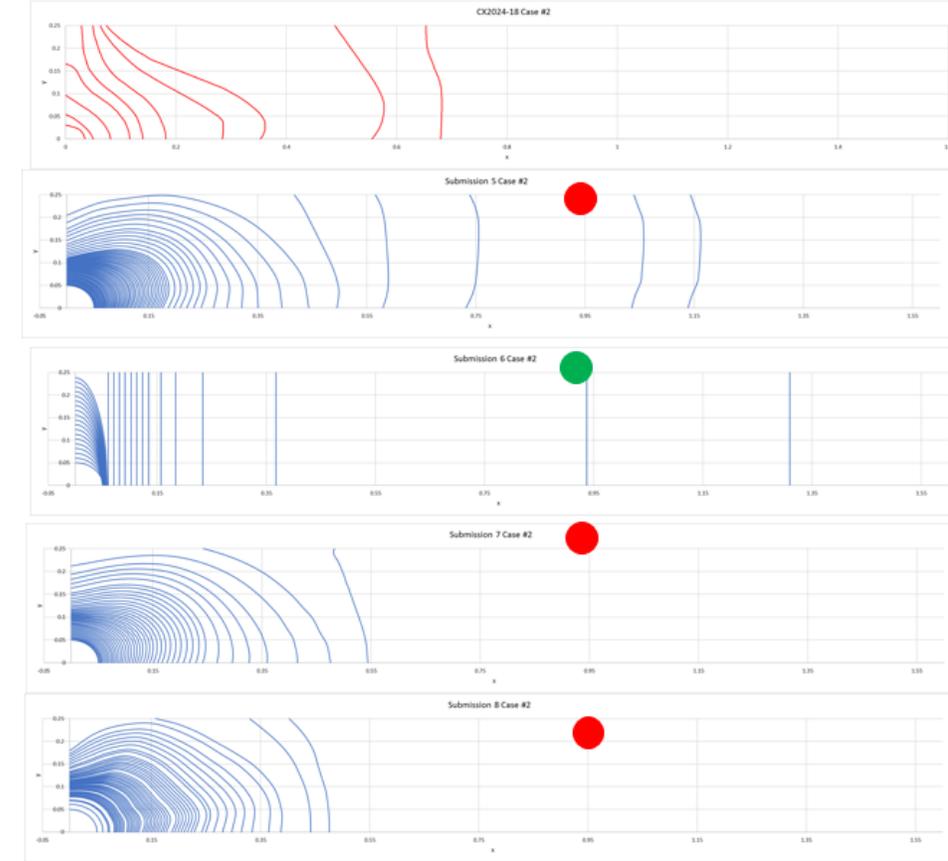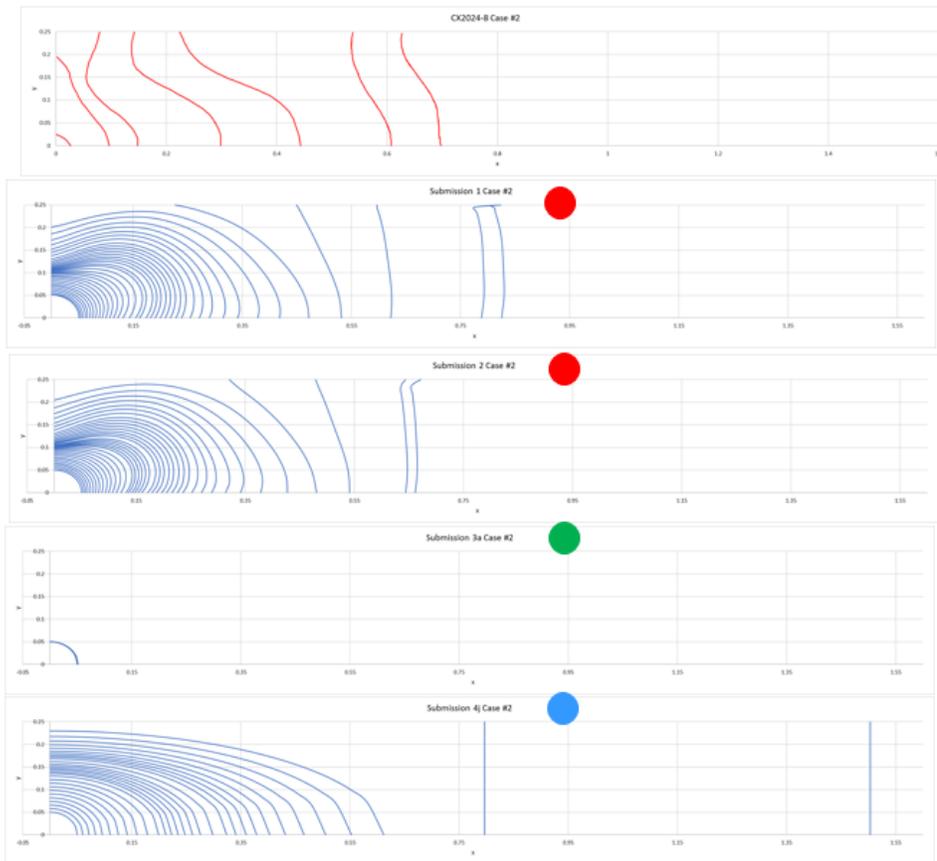
- Tests demonstrated stable crack growth after transition to a thru thickness crack, but that was largely not the case for analyses

Round Robin for Cx Holes – Case #2

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Case #3

Short Edge Margin Hole (e/D = 1.2)

Full Life   **Corner Crack only**   **Thru Crack only**
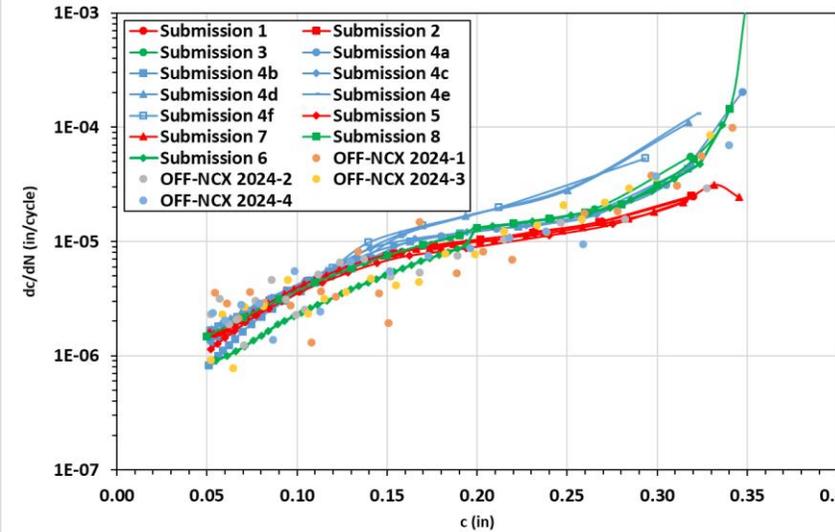

Test data only

- Significantly more spread in analysis than test data. Analysis varies by a factor of ~2, whereas test data only varies by ~10%
- Analyses transitioned to thru cracks with shorter "c" cracks than test. Tests went up to 0.25" with corner cracks but analyses generally transitioned around 0.15"
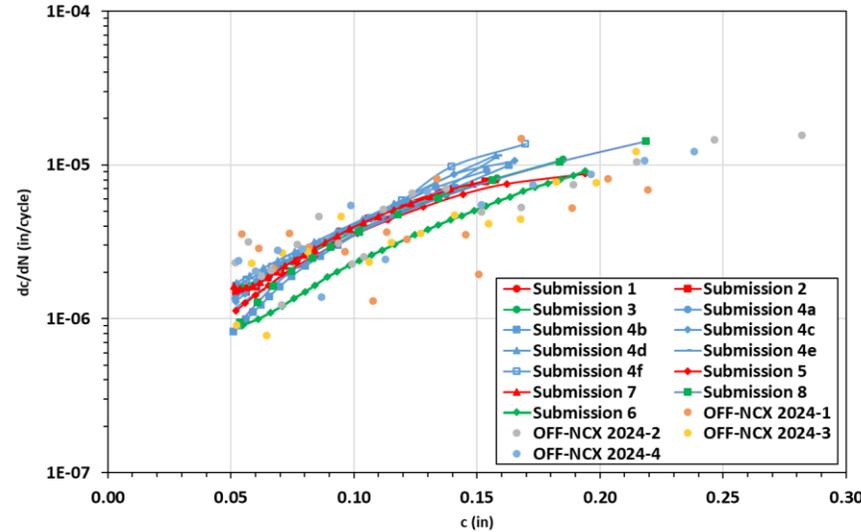- Once a thru crack, test data generally went to failure faster than analyses.

Full Life

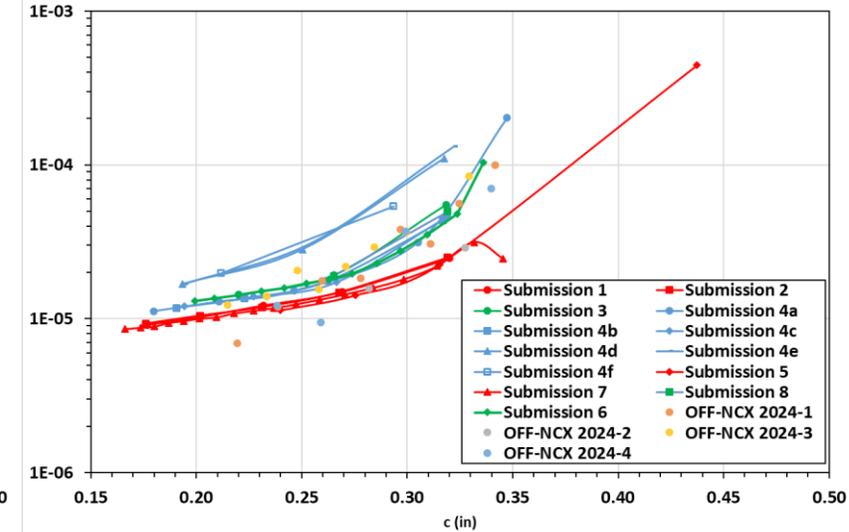

Case #3 - Full Life - dc/dN vs. c

Corner Crack only

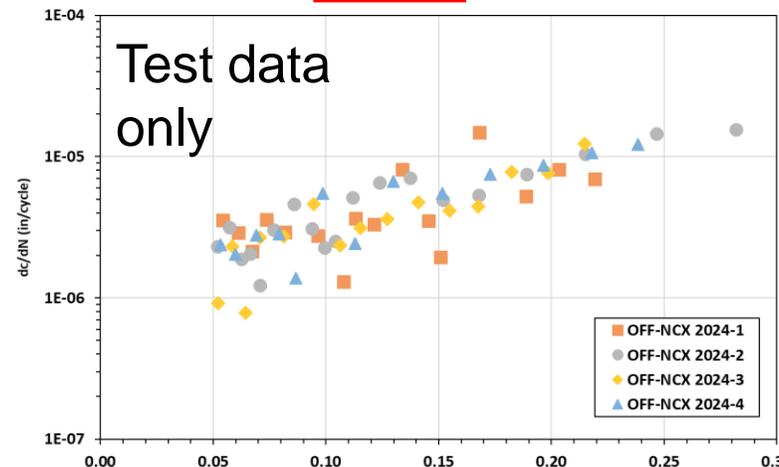Case #3 - Corner Crack Only - dc/dN vs. c

Thru Crack only

Case #3 - Thru Crack Only - dc/dN vs. c

- Test growth rates for corner cracks varied significantly within the same test. In the plot of just test data you can see that each test specimen has data points at both the top and bottom end of the grouping
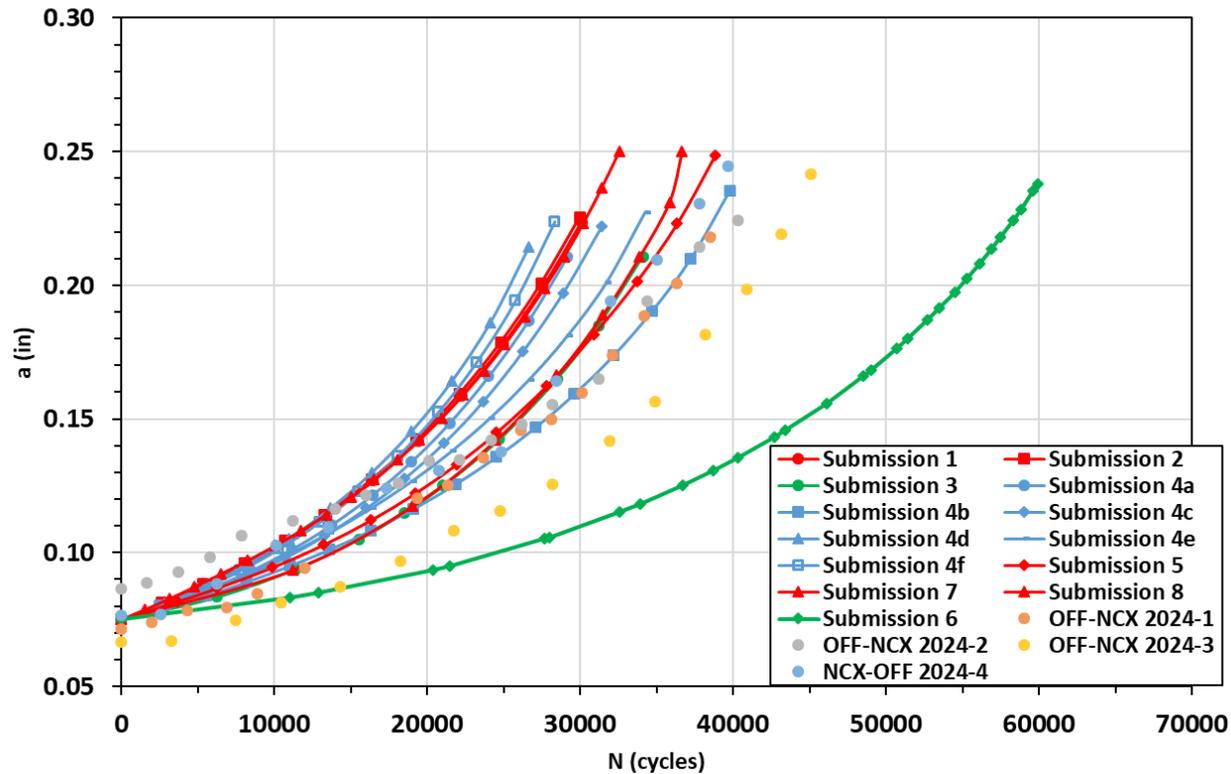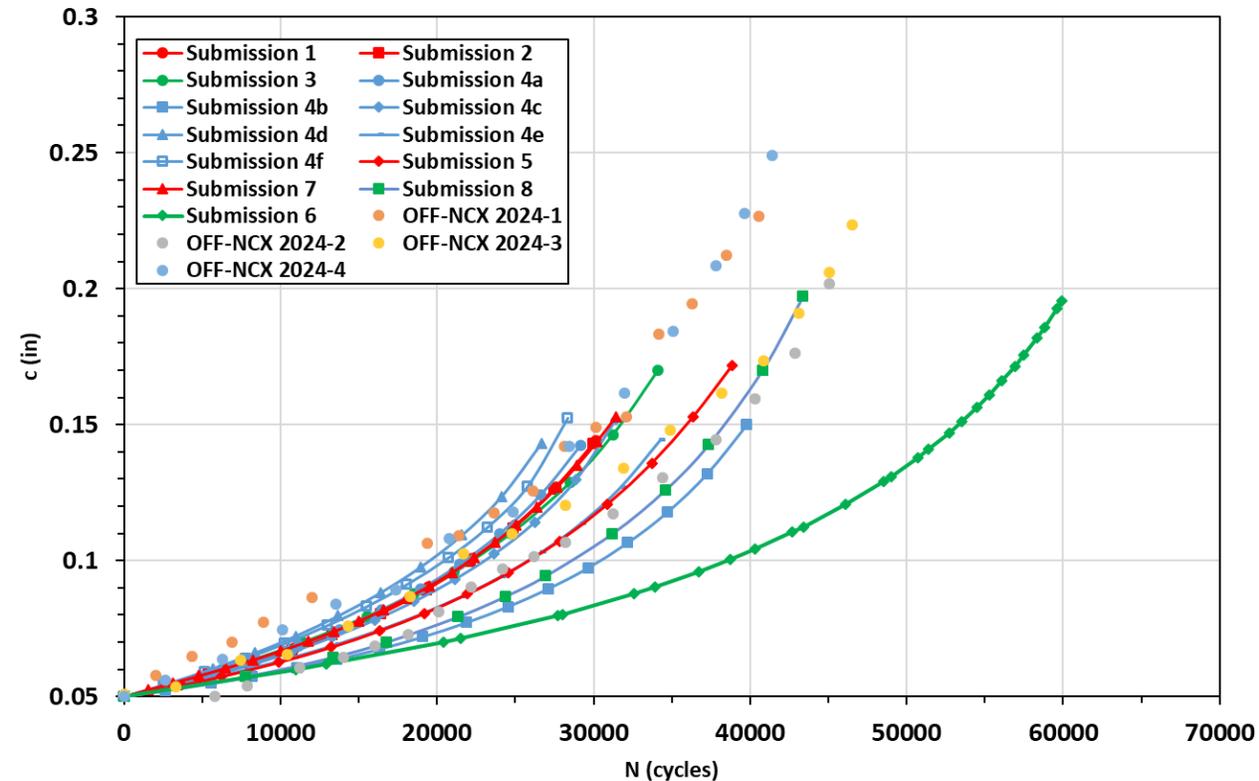

Case #3 - Corner Crack Only - dc/dN vs. c

Test data only

Case #3 - a vs. N

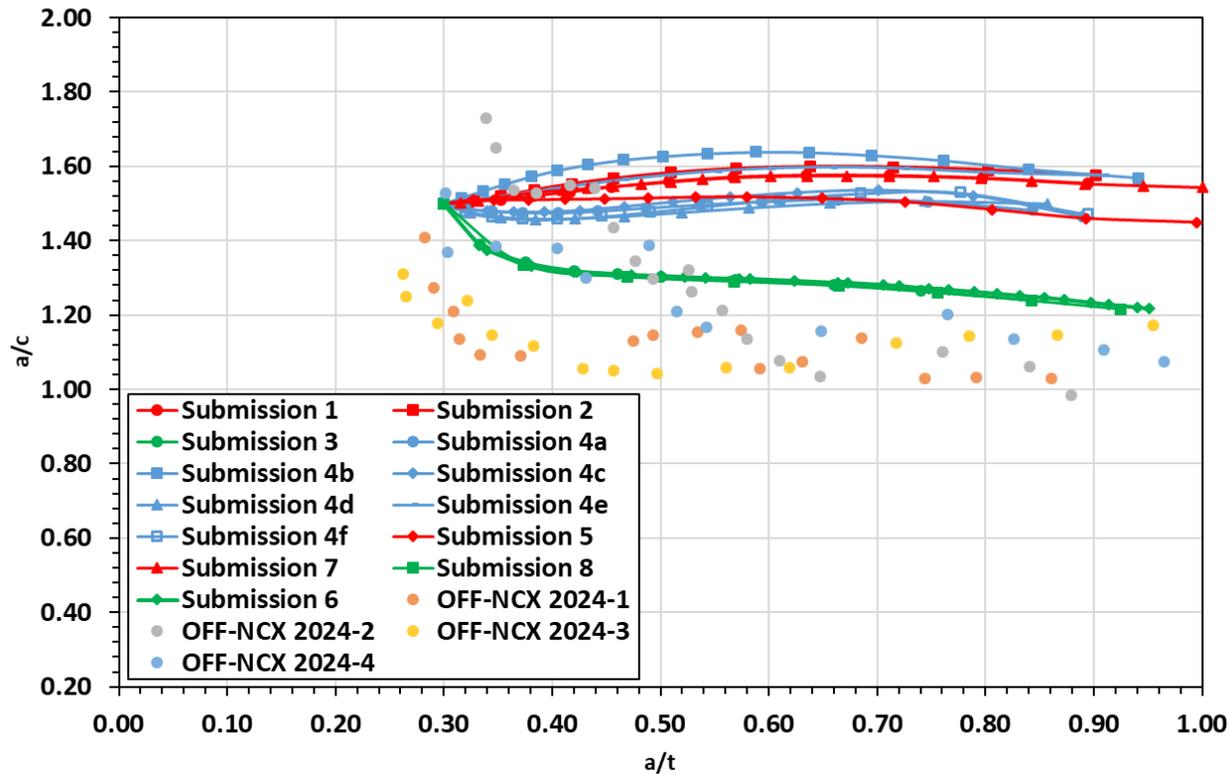Case #3 - Corner Crack Only - c vs. N

- Again, as observed in Case #1, test data grows to longer surface lengths than analyses prior to transitioning to a thru crack. Interesting the range is roughly the same, tests transition when "c" is ~0.25" while analyses generally transition around 0.15"
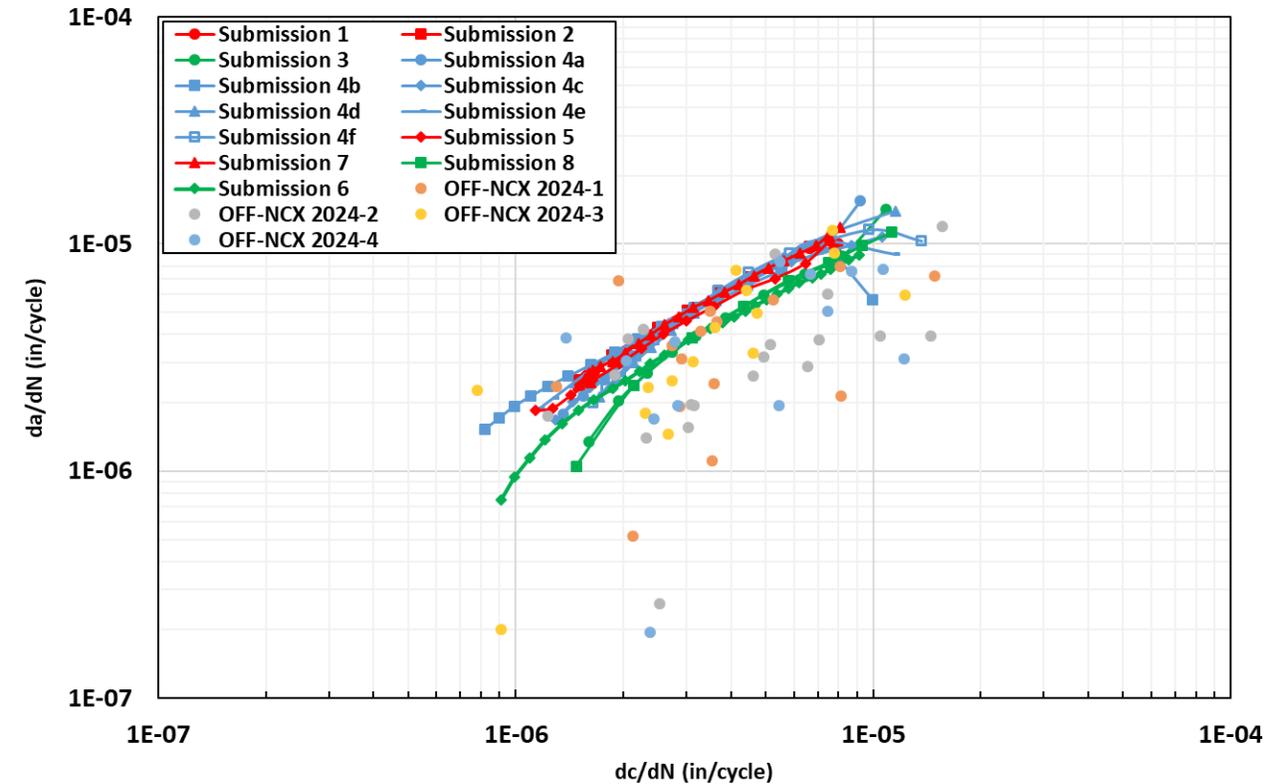
Case #3 - a/c vs. a/t

Case #3 - da/dN vs. dc/dN

- Test specimens 1 and 3 follow one curve shape on the left plot and tests 2 and 4 follow another, then the two merge around a/t > 0.5
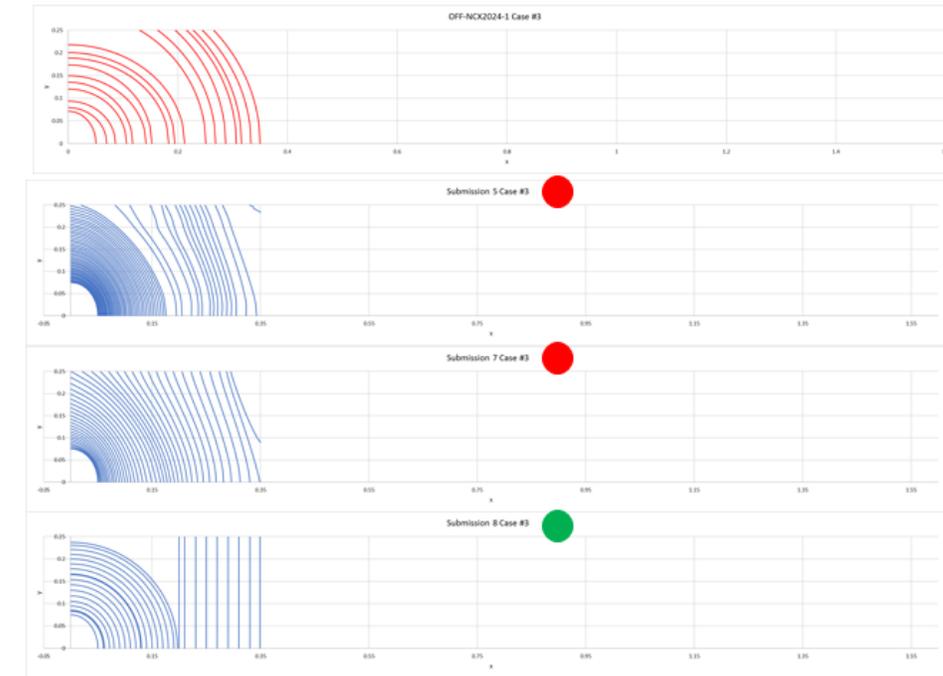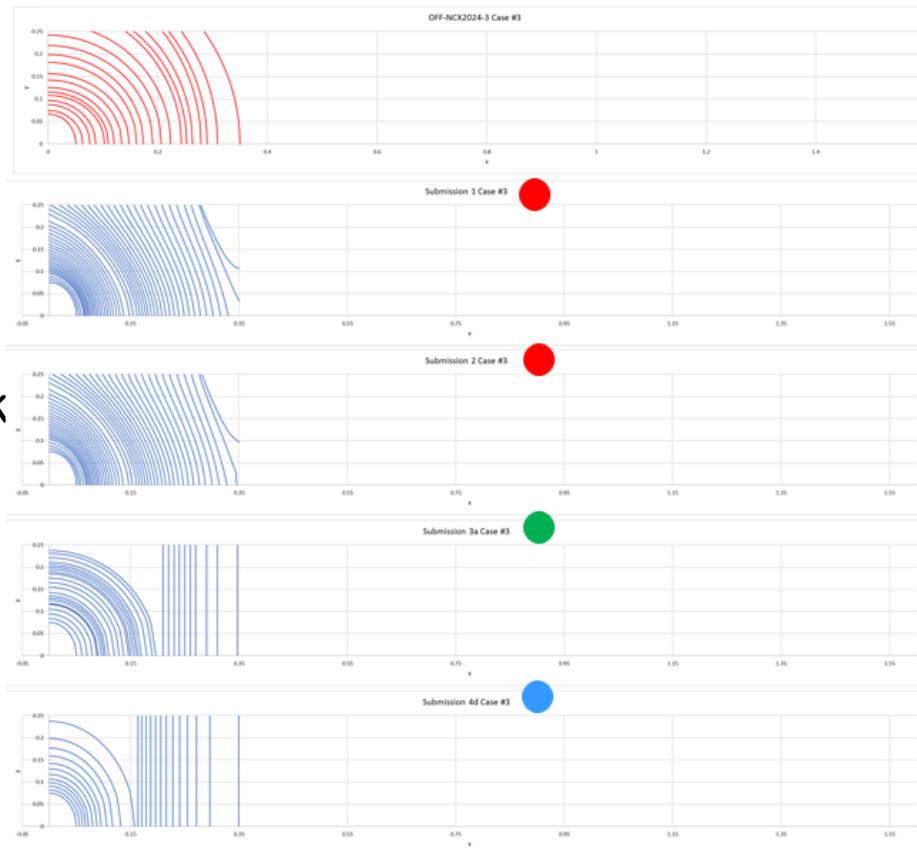- Each test has values at both the high and low ends of the data range in the rate plot

- It may be helpful to visualize crack progression in these plots if analysis crack fronts are shown at the same cycle count as the crack fronts from the test data

Round Robin for Cx Holes – Case #3
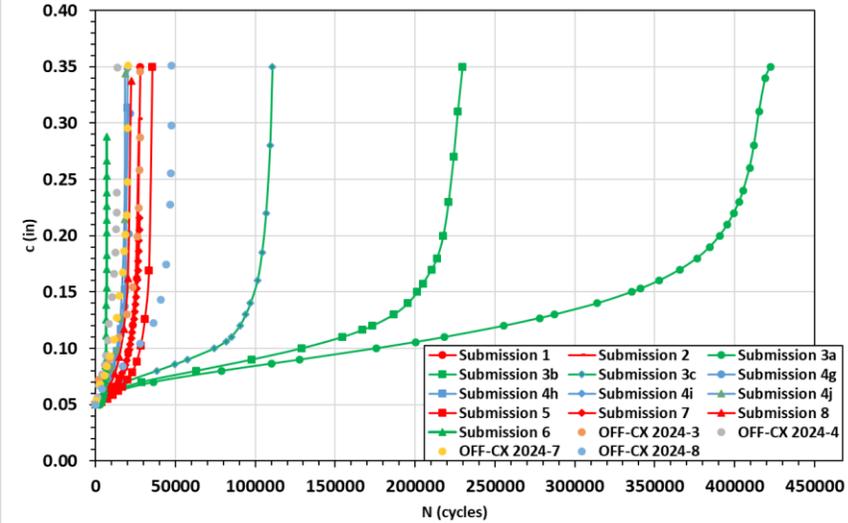
20

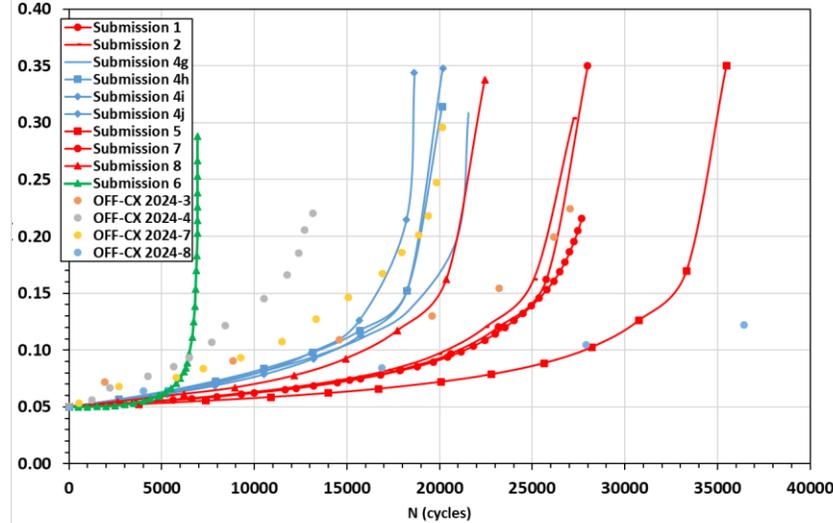# Cold Expanded Short Edge Margin Hole (e/D = 1.2)

Case #4
Surface Crack "c"

Full Life	Corner Crack only	Thru Crack only
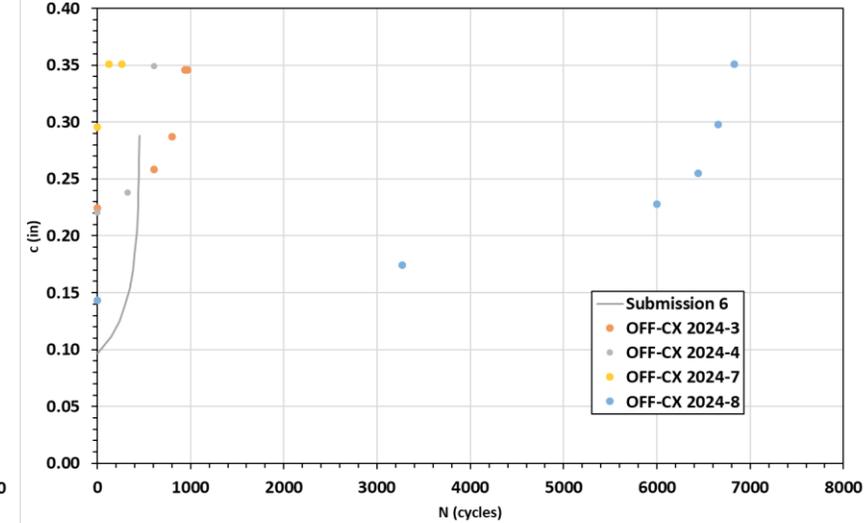
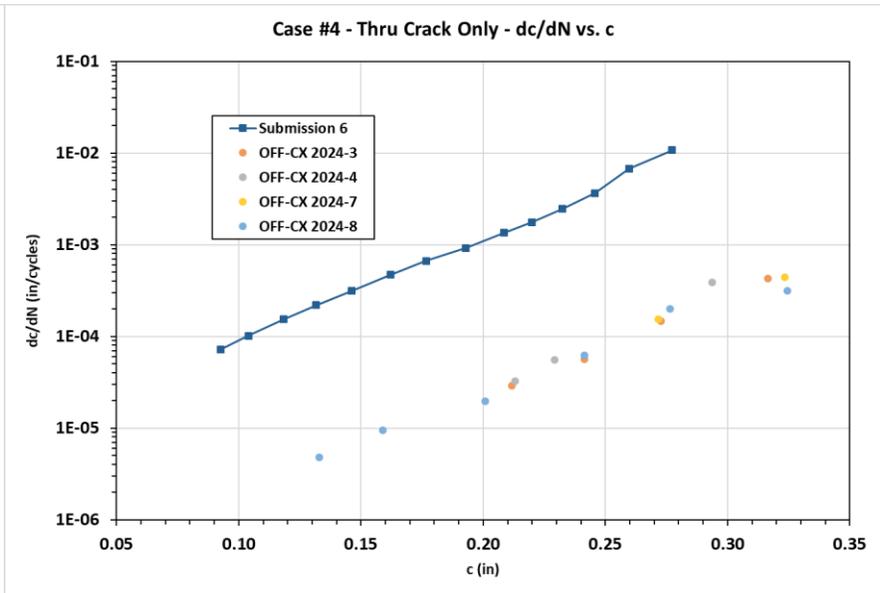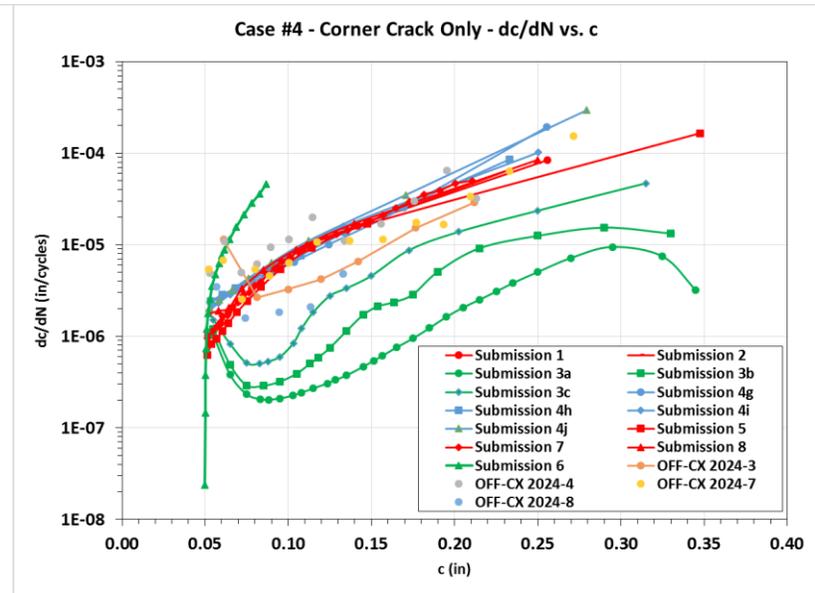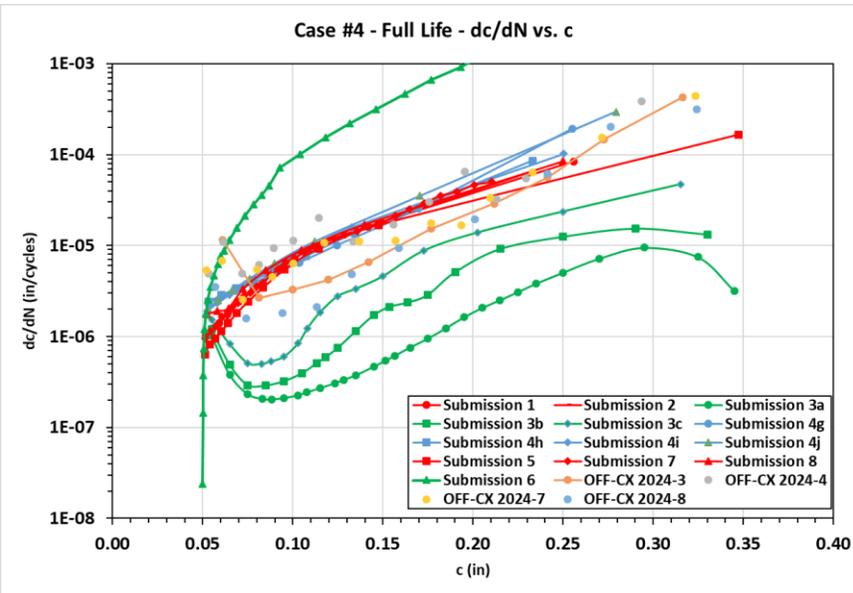- Only case where some predictions were significantly unconservative, factor of ~8

Case #4
dc/dN Comparisons

Full Life   Corner Crack only   Thru Crack only
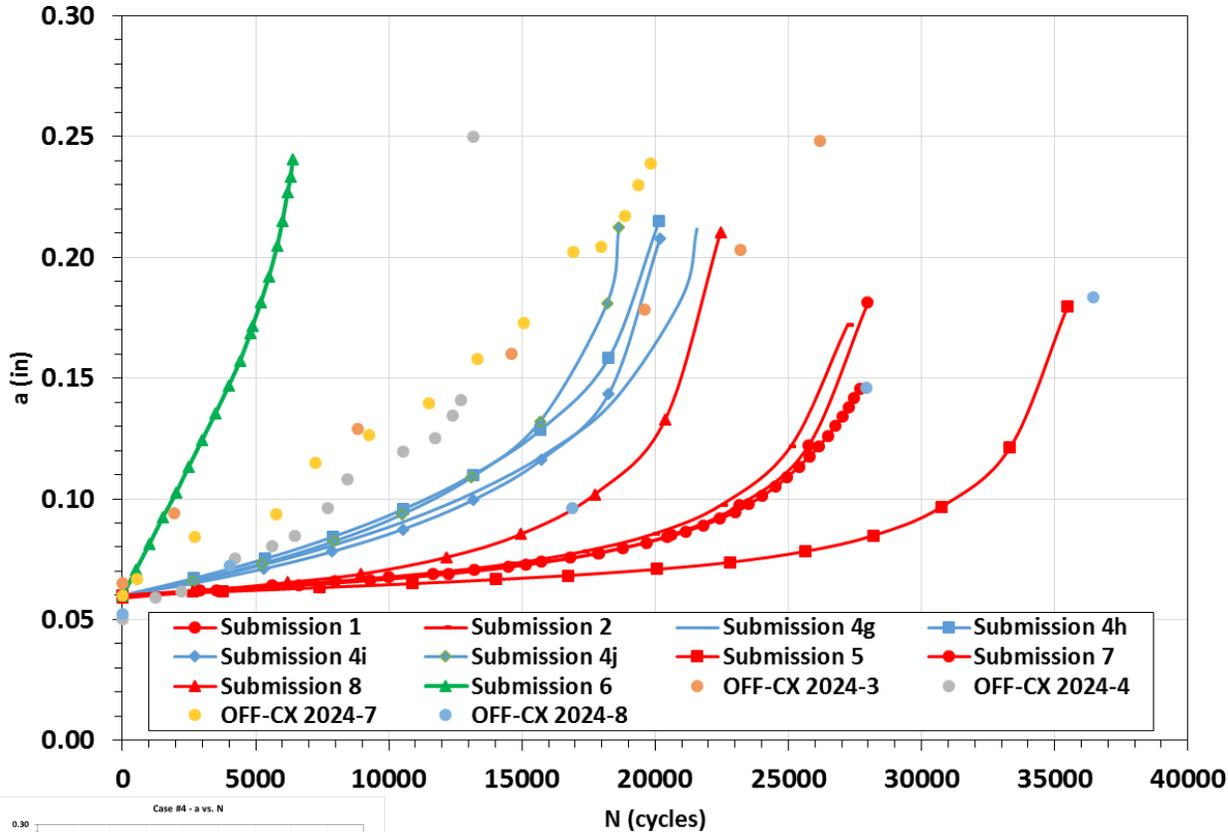

- All tests had some growth after transitioning to a thru thickness crack, but most analyses did not
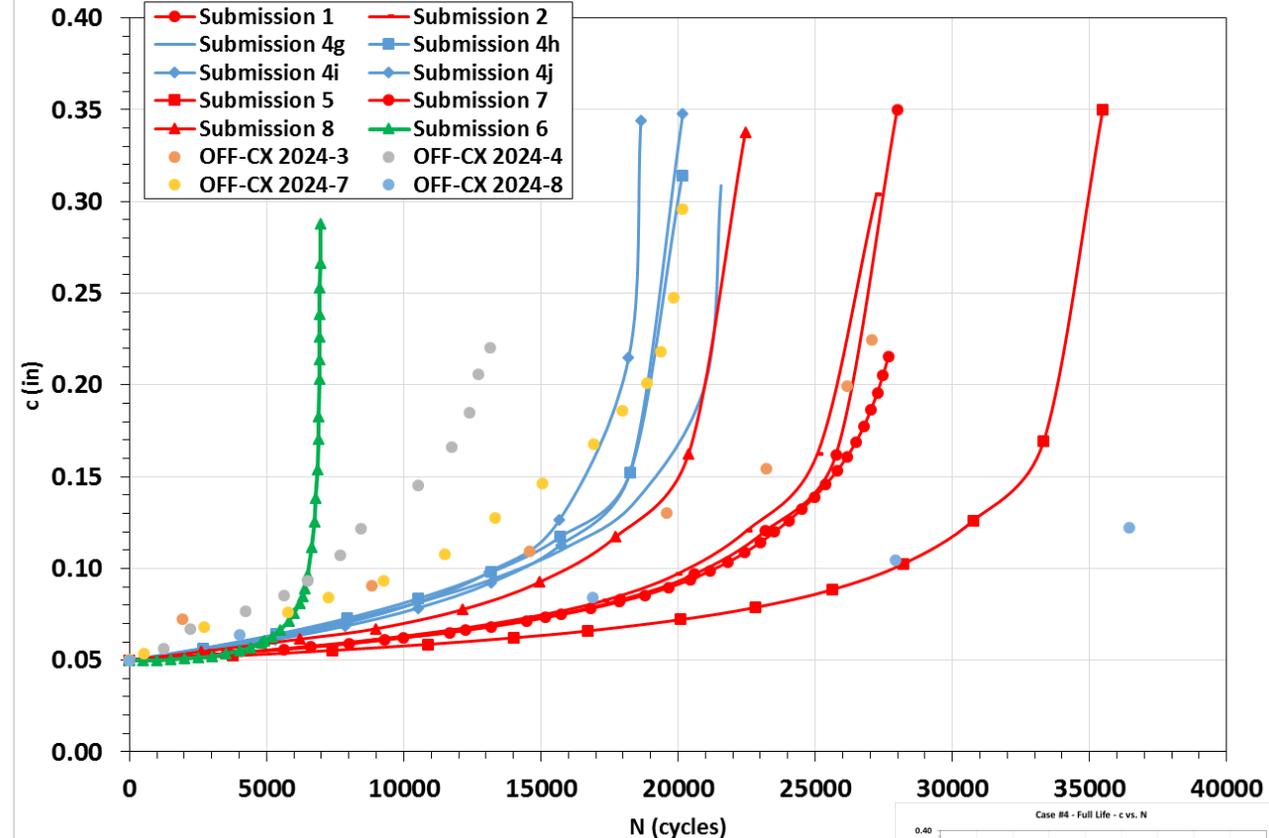
Case #4 - a vs. N

Case #4 - Corner Crack Only - c vs. N

- One set of submissions are only shown in small plots because they had significantly longer lives, up to 420,000
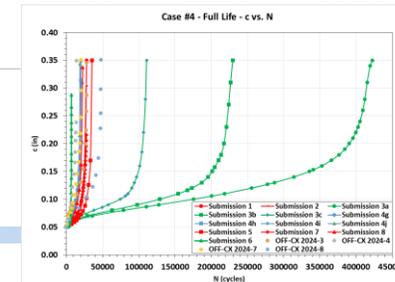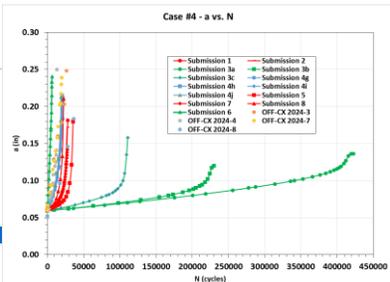
Case #4 - a/c vs. a/t

Case #4 - da/dN vs. dc/dN
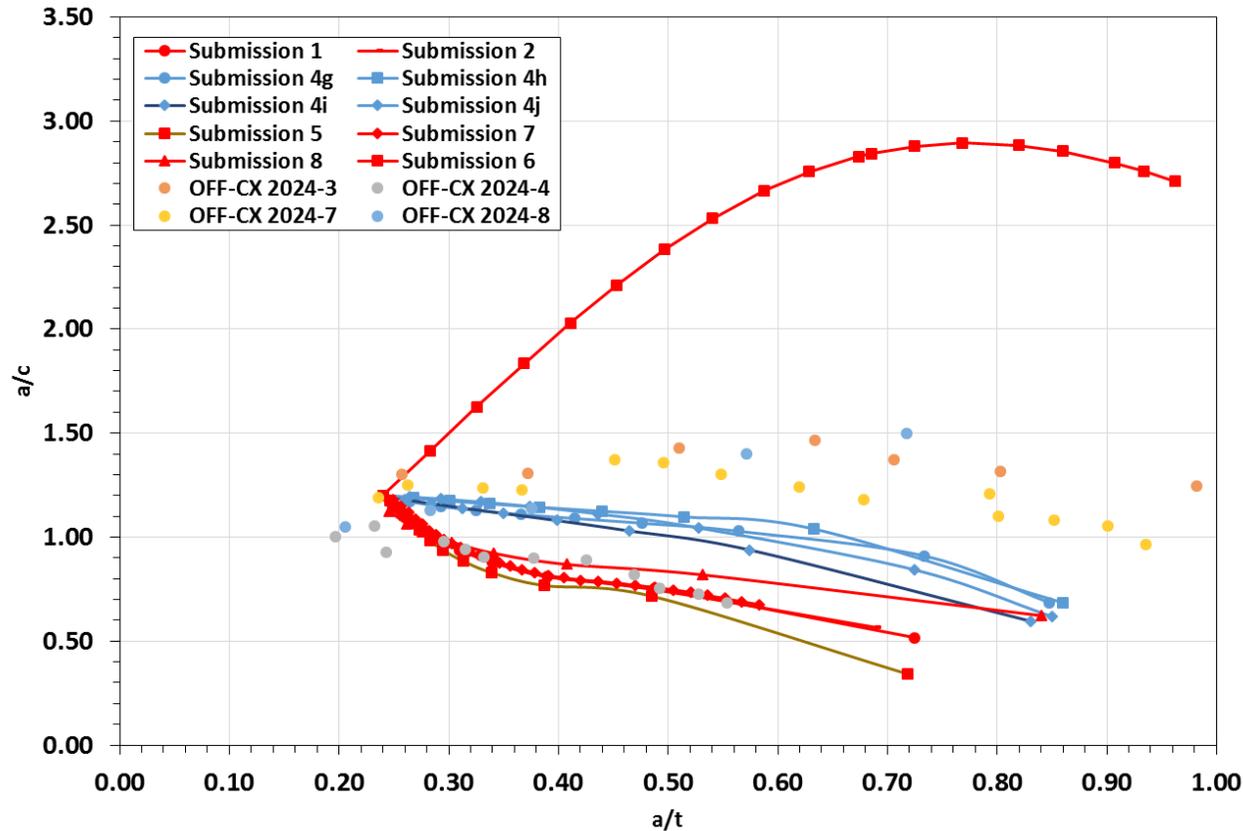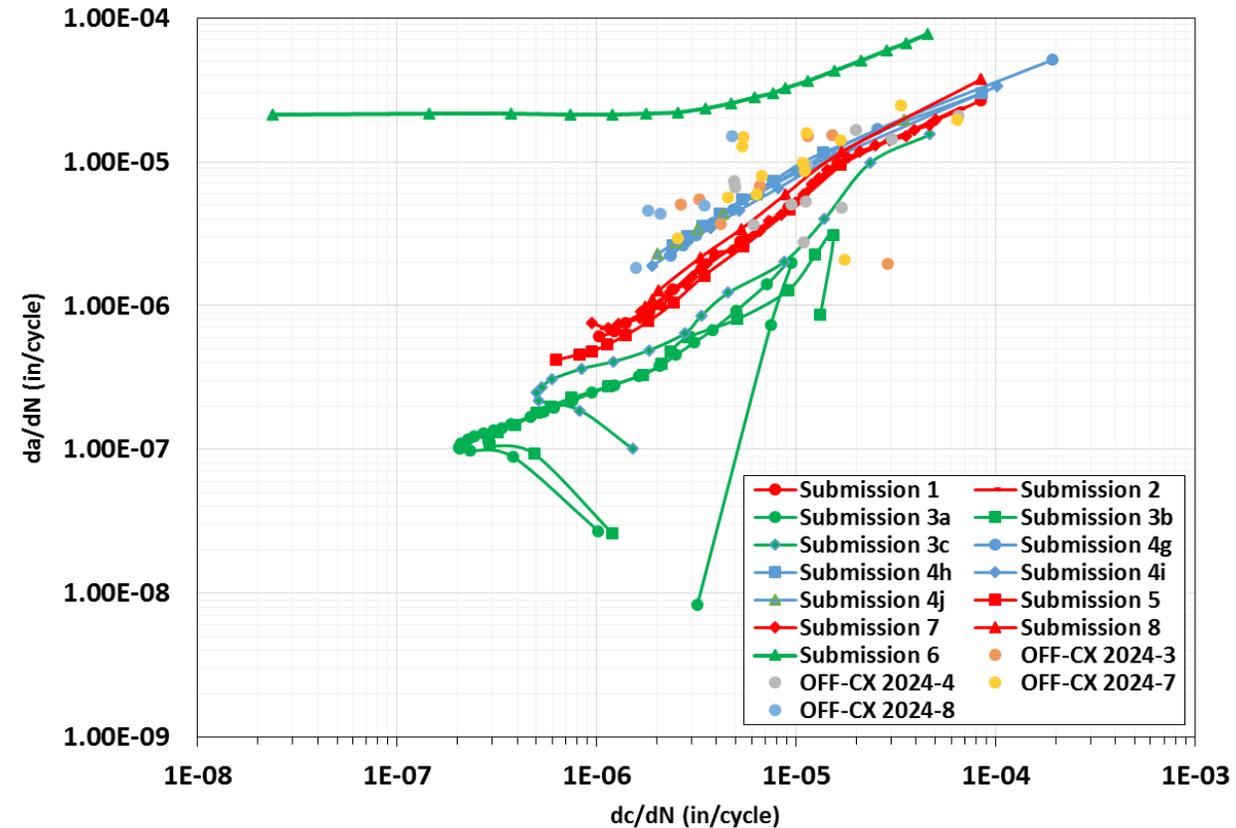
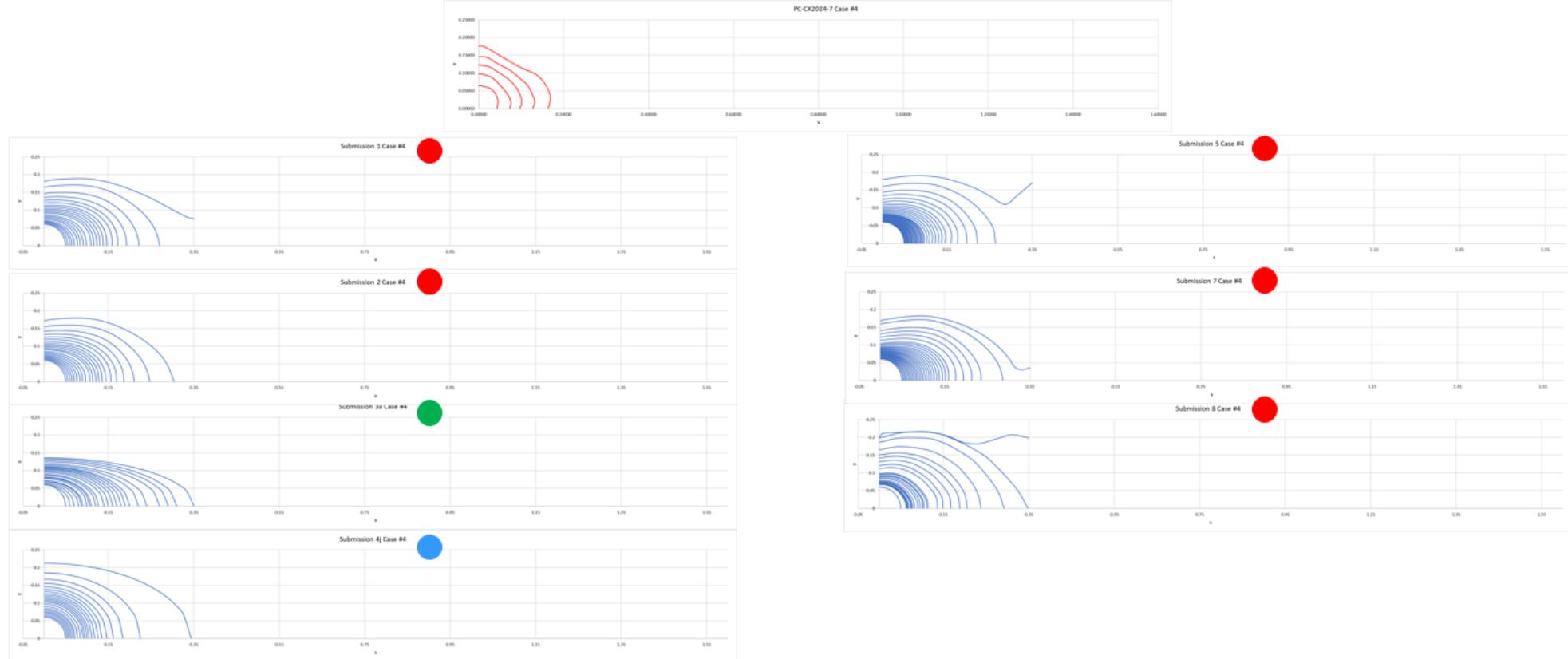- Significant scatter for analysis rates (da/dN vs dc/dN plot) while test data is more tightly grouped

- Essentially all analyses nearly pinned the "a" crack, but the same is not shown in the test

Round Robin for Cx Holes – Case #4

Conclusions

- **For non-CX cases (Cases 1, 3) test surface crack lengths were significantly longer than analysis surface crack lengths at transition to a thru crack**
  - **Test data transitioned around 0.25" while analysis data transitioned around 0.15"**
- **For both CX cases (Cases 2, 4) test data had stable growth after becoming a thru crack, while most analyses went to failure**
- **For da/dN vs. dc/dN plots, non-CX cases had test data generally below analysis data, while the opposite was true for CX cases**
- **For Case #2, dc/dN vs. "c" test data was tightly grouped around c=0.1", while most analysis data ran off to higher rates and crack lengths correlating with failure at or before transition to a thru crack**

Recommendations

- **Investigate why analyses predict transition to a thru crack earlier than test for non-CX cases**
- **Research how to modify analyses to have stable crack growth after transition to a thru crack as was seen in test data**
- **Evaluate why da/dN vs. dc/dN analytical data was high for Non-CX and low for CX scenarios**
- **Investigate causes for analytical scatter in Case #3**
  - **Test data had minimal scatter, but analyses did not**
  - **Potentially create some recommended settings/approaches for analyzing short edge margin geometries**