

# 2014 AFGROW Workshop – Layton, UT.

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## Sensitivity Study of Parameters Influencing BAMF Predictions within a Deep Residual Stress Field Caused by Cold Expansion

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# Acknowledgements

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- Southwest Research Institute – Dallen Andrew

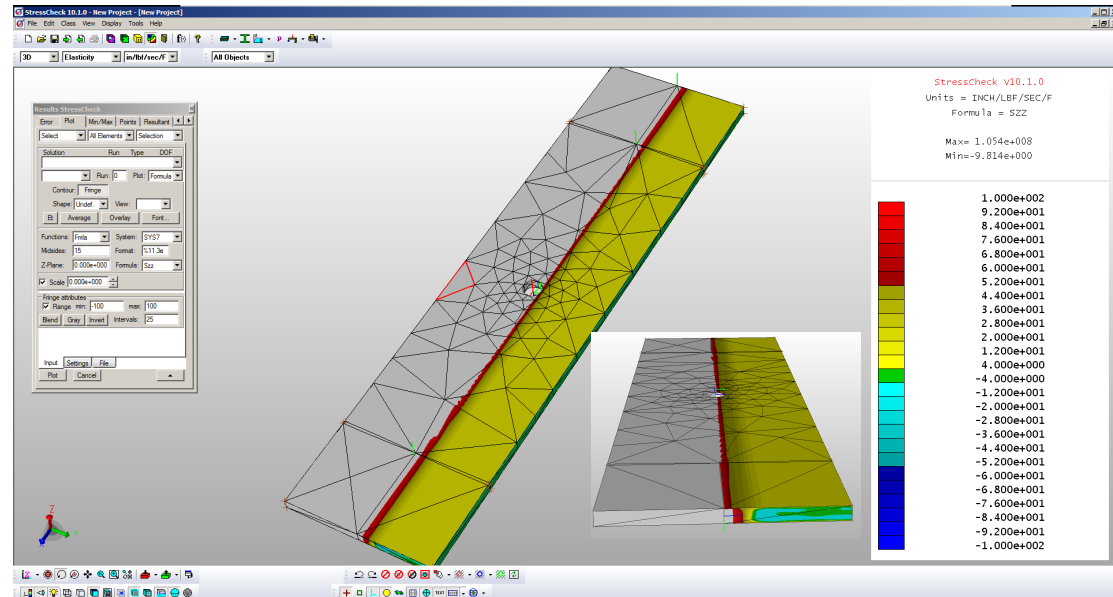
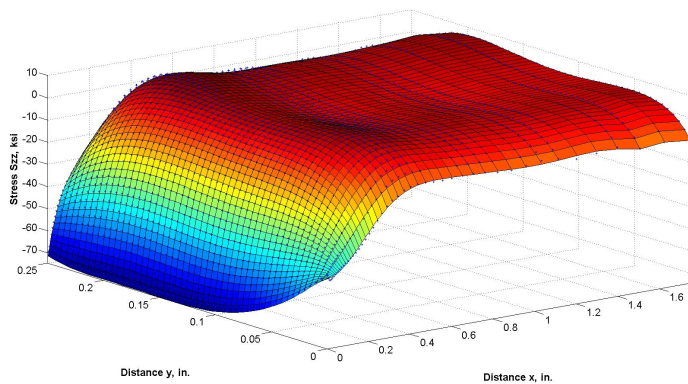
# Agenda

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- Validation Testing of BAMF Compared to Test Data
  - Carlson, Warner & Andrew Thesis Data
  - APES CP44 Short Edge Margin Data
- A Look at Factors of Influence
- Initial Load Interaction Study
- Lessons Learned

# Validation Data for BAMF

- StressCheck<sup>®</sup> 10.1 Allows for Inclusion of Residual Stress as a Crack Face Traction
- Residual Stress Data Provided by Hill Eng. Inc. Through Contour Method



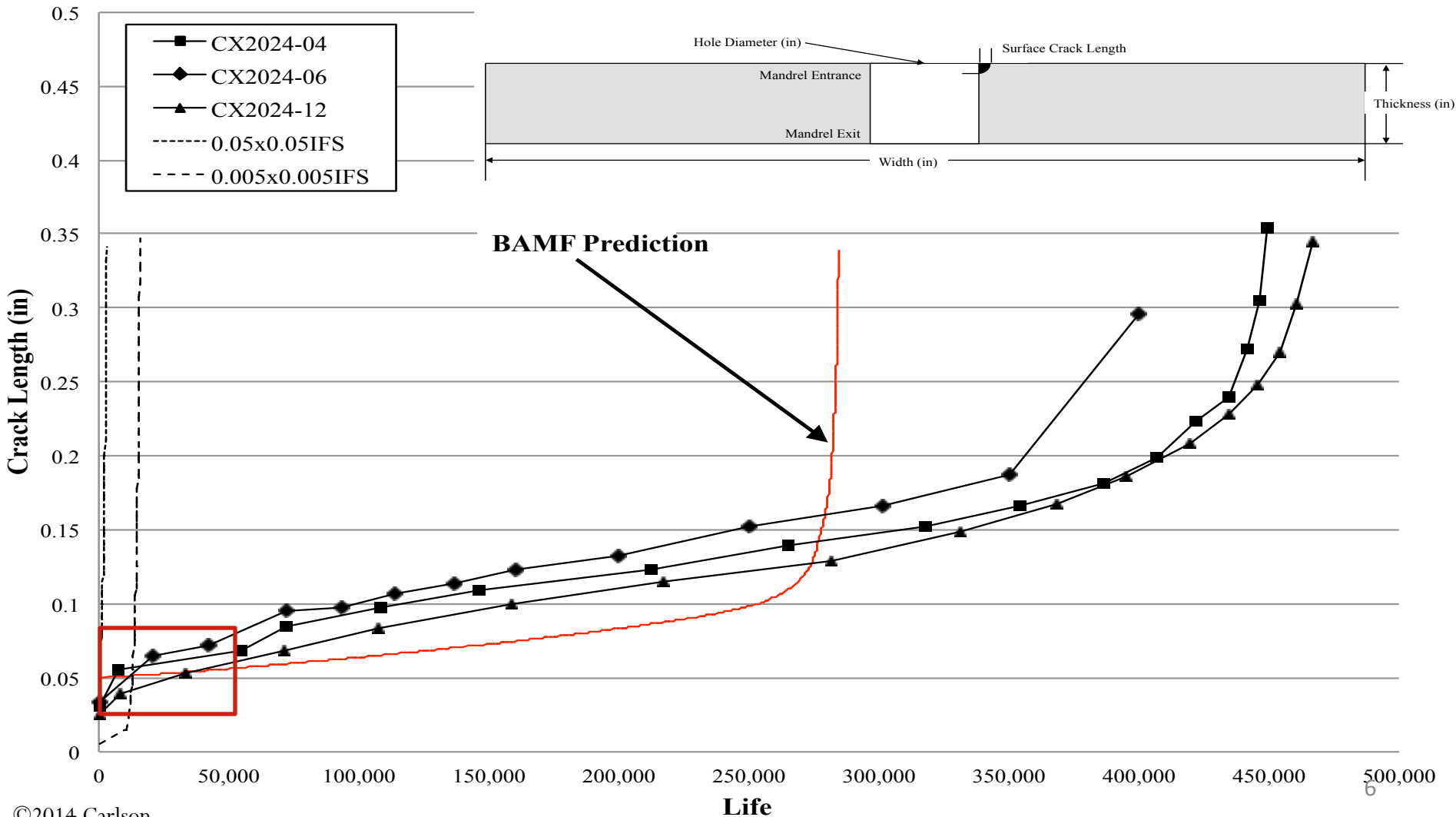
# 2024-T351 Centered Hole Coupons

- Modeling Parameters

Material File	Max Stress (ksi)	Loading Condition	Length (in)	Width (in)	Thickness (in)	Hole Diameter (in)	Edge Margin	Percent Growth	P-Level	Shape Type
2024-T351 A-10 Mat	25	Constant Amplitude	16	4	0.25	0.5	4	3	3	Multi-Point
	33	Variable Amplitude	16	4	0.25	0.5	4	3	3	Multi-Point
	43.25	Variable Amplitude	16	4	0.25	0.5	4	3	3	Multi-Point
	25	Constant Amplitude	16	4	0.25	0.5	1.2	3	3	Multi-Point
	33	Variable Amplitude	16	4	0.25	0.5	1.2	3	3	Multi-Point

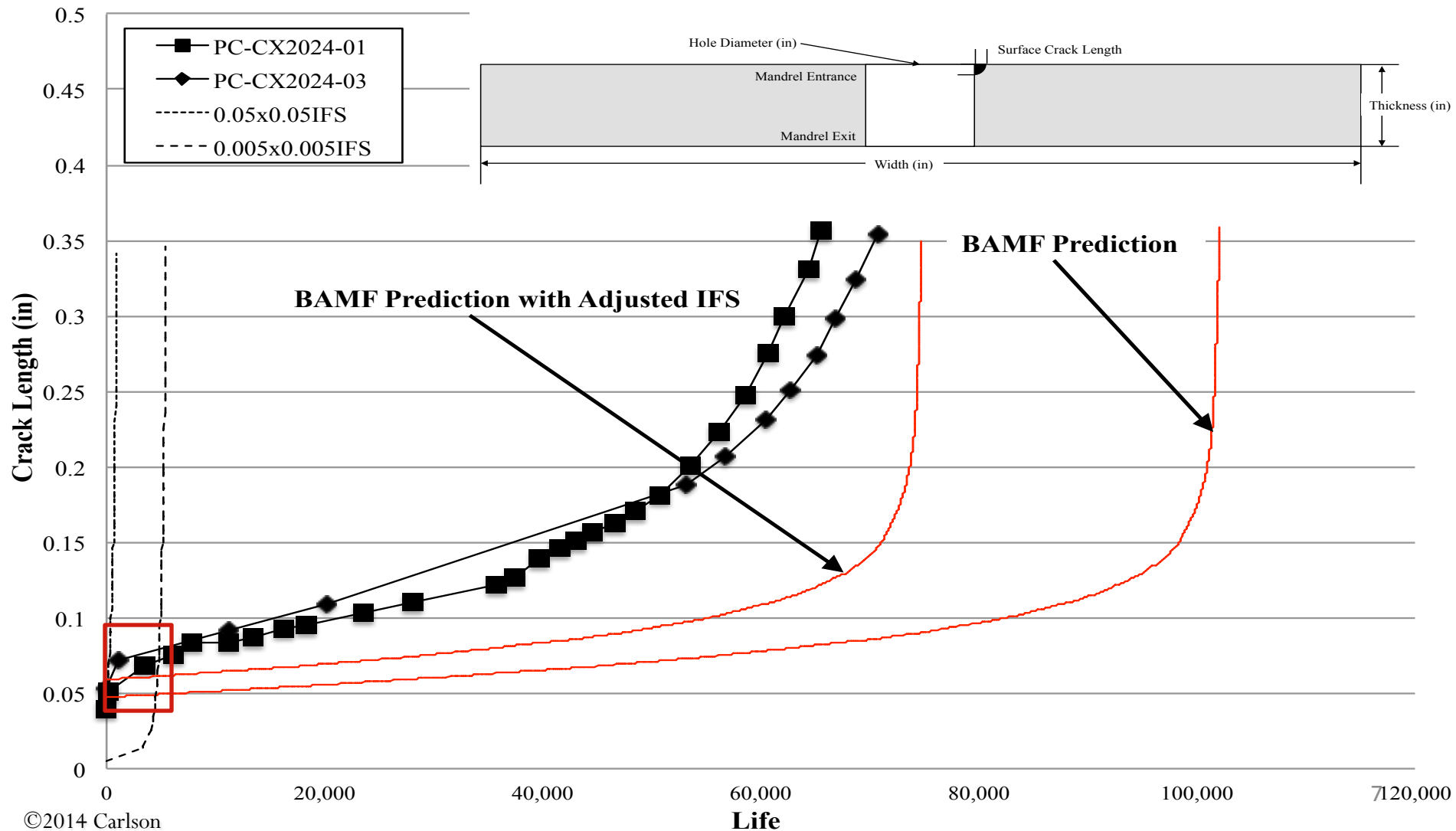
# 2024-T351 Center Hole Data

**Fatigue Crack Growth Test Data Showing BAMF Prediction for 4.0 Edge Margin Constant Amplitude Max Stress = 25ksi, R=0.1**



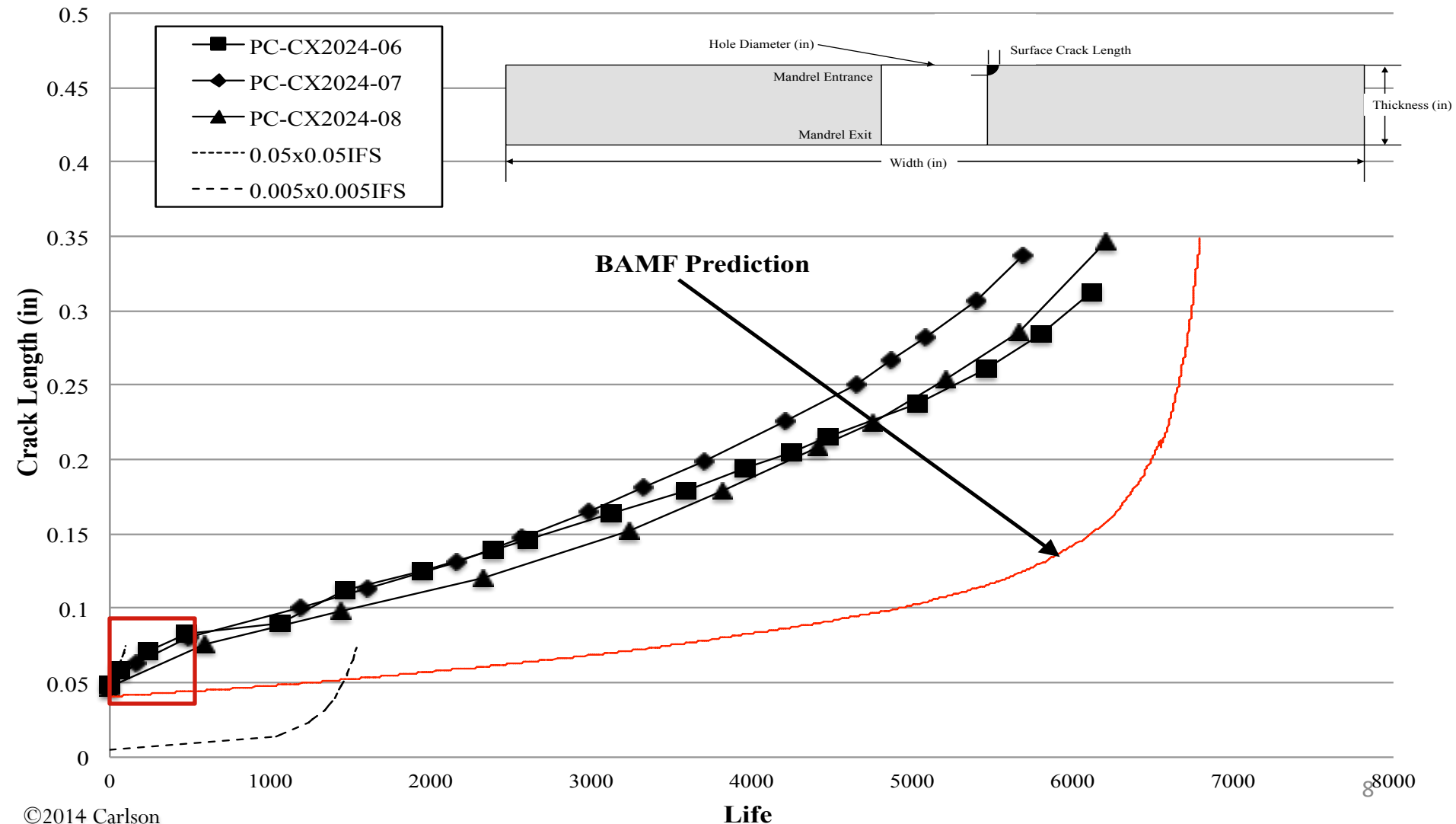
# 2024-T351 Center Hole Data

**Fatigue Crack Growth Test Data Showing BAMF Prediction for Edge Margin for 4.0 Edge Margin Variable Amplitude 33ksi Max Stress**



# 2024-T351 Center Hole Data

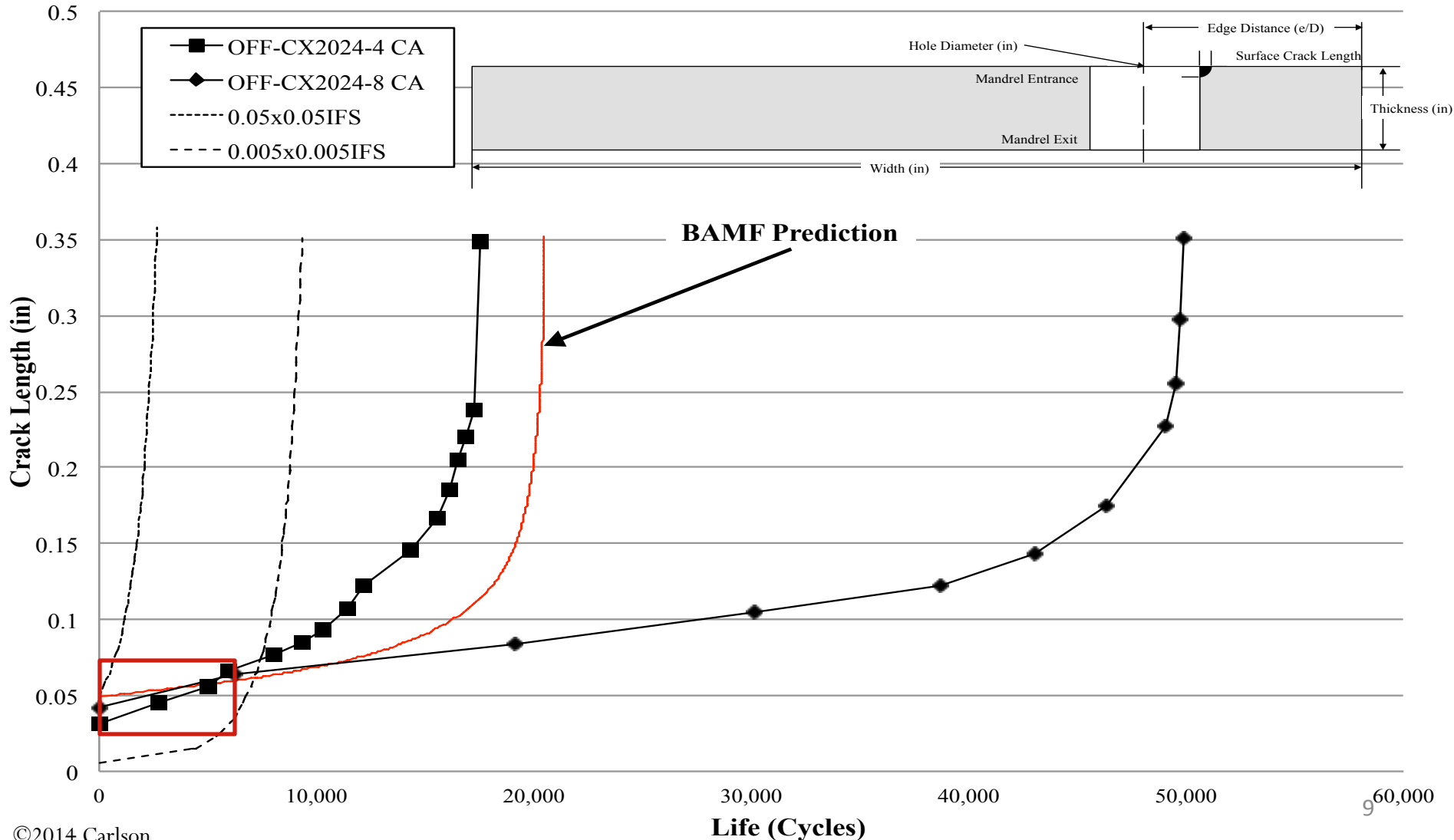
**Fatigue Crack Growth Testing Data Showing BAMF Prediction for 4.0  
Edge Margin Variable Amplitude Max Stress 43.25ksi**





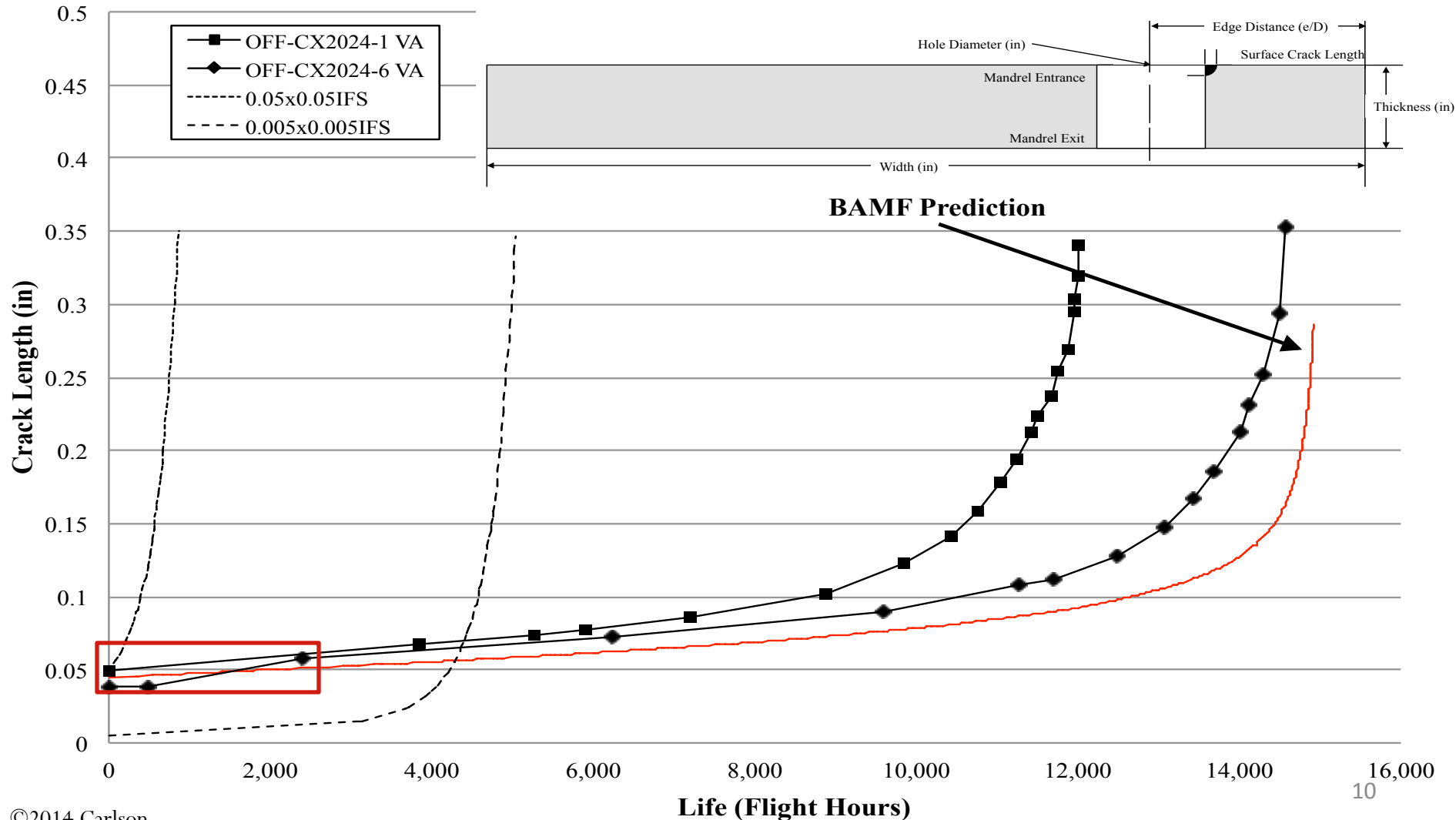
# 2024-T351 1.2 Edge Margin

Fatigue Crack Growth Test Data Showing BAMF Prediction for 1.2 Edge Margin Constant Amplitude Max Stress 25ksi, R=0.1



# 2024-T351 1.2 Edge Margin

## Fatigue Crack Growth Test Data Showing BAMF Prediction for 1.2 Edge Margin Variable Amplitude 33ksi Max Stress



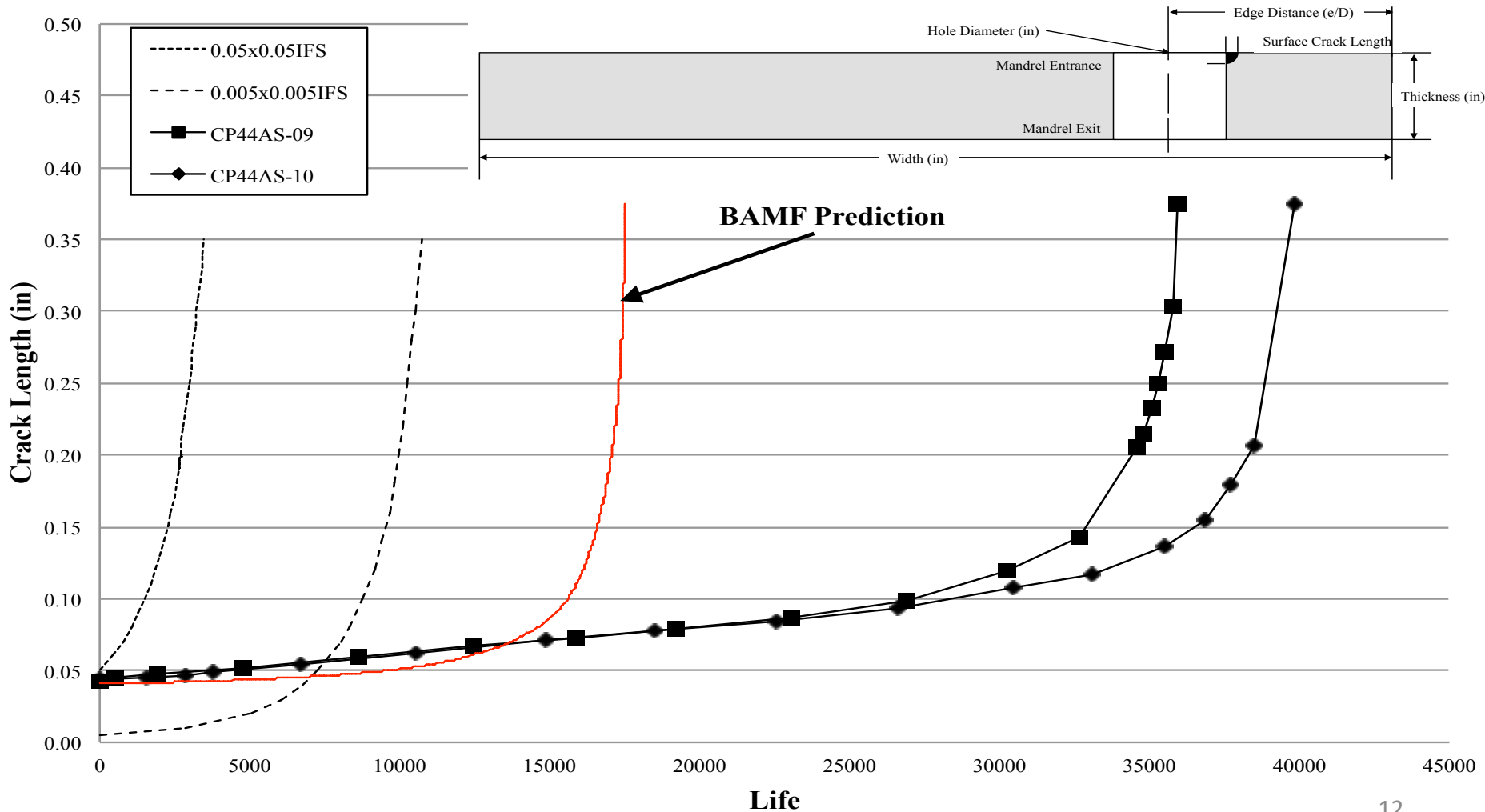
# 2024-T351 CP44 Short Edge Margin

- Modeling Parameters

<b>Material File</b>	<b>Max Stress (ksi)</b>	<b>Loading Condition</b>	<b>Residual Stress Level</b>	<b>Length (in)</b>	<b>Width (in)</b>	<b>Thickness (in)</b>	<b>Hole Diameter (in)</b>	<b>Edge Margin</b>	<b>Percent Growth</b>	<b>P-Level</b>	<b>Shape Type</b>
APES Mat File	28	Variable Amplitude	Max	11	5.5	0.19	0.375	1.5	3	3	Multi-Point
			Min	11	5.5	0.19	0.375	1.5	3	3	Multi-Point
			Min	11	5.5	0.19	0.4375	1.28	3	3	Multi-Point

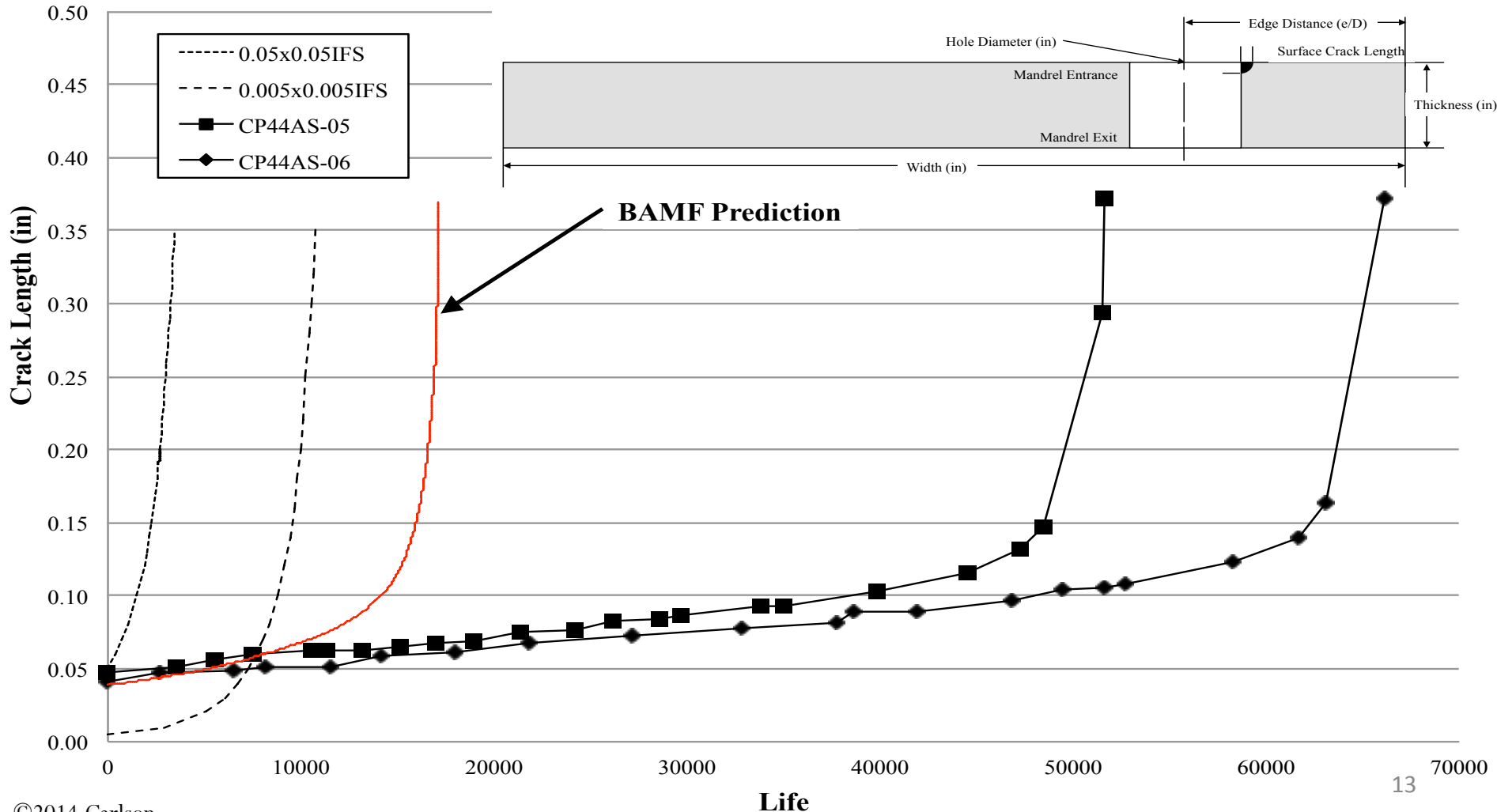
# 2024-T351 CP44 Short Edge Margin

**Fatigue Crack Growth Test Data Showing BAMF Prediction for 1.5 Edge Margin, Dia. 0.375in, Variable Amplitude 28ksi Max Stress, Min Applied Expansion**



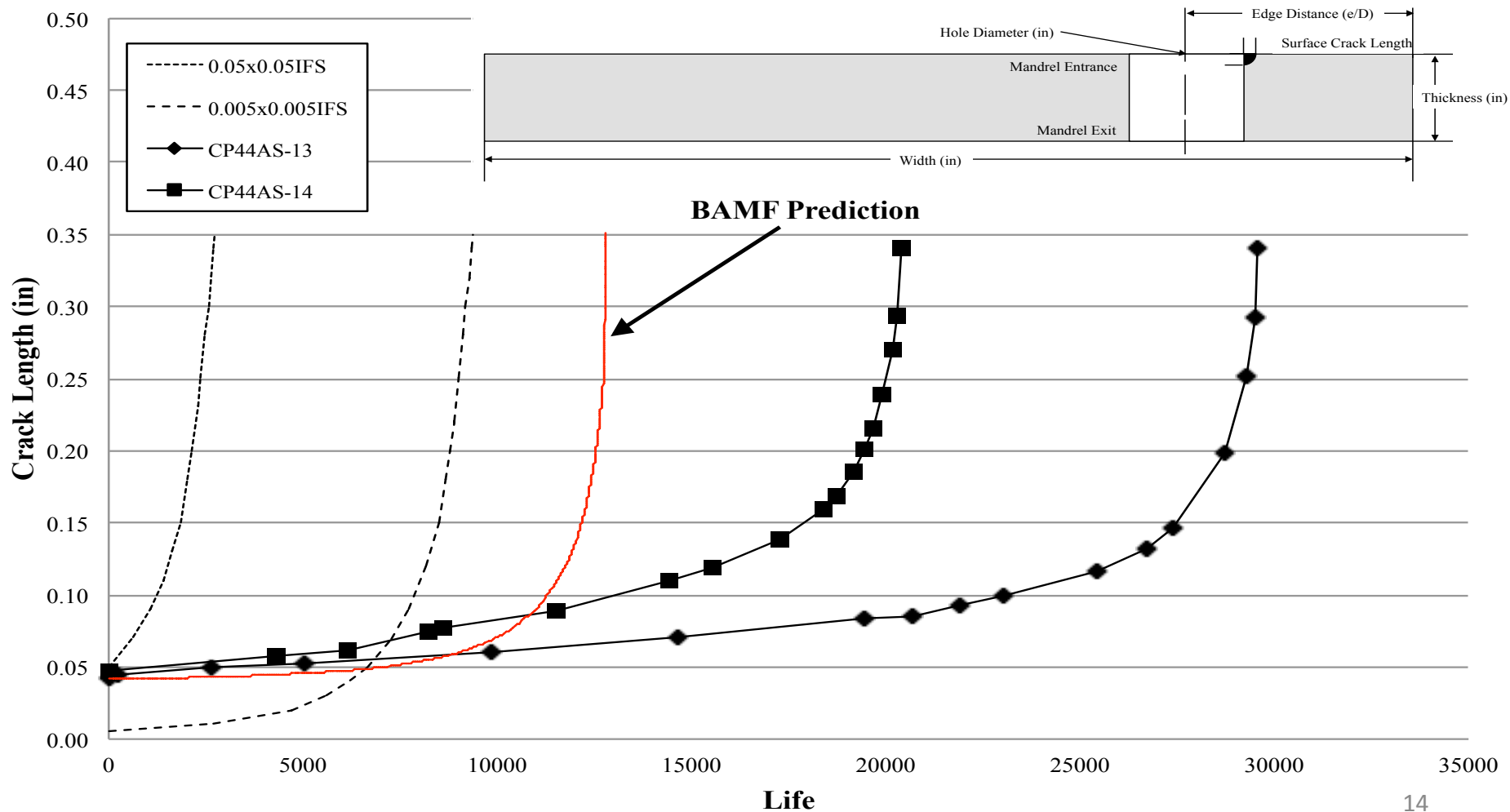
# 2024-T351 CP44 Short Edge Margin

Fatigue Crack Growth Test Data Showing BAMF Prediction for 1.5 Edge Margin, Dia. 0.375, Variable Amplitude 28ksi Max Stress, Max Applied Expansion



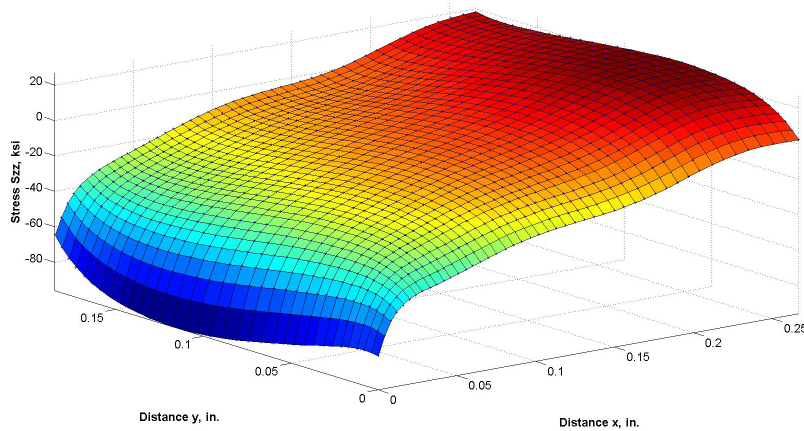
# 2024-T351 CP44 Short Edge Margin

**Fatigue Crack Growth Test Data Showing BAMF Prediction for 1.28 Edge Margin, Dia. 0.4375in, Variable Amplitude 28ksi Max Stress, Max Applied Expansion**

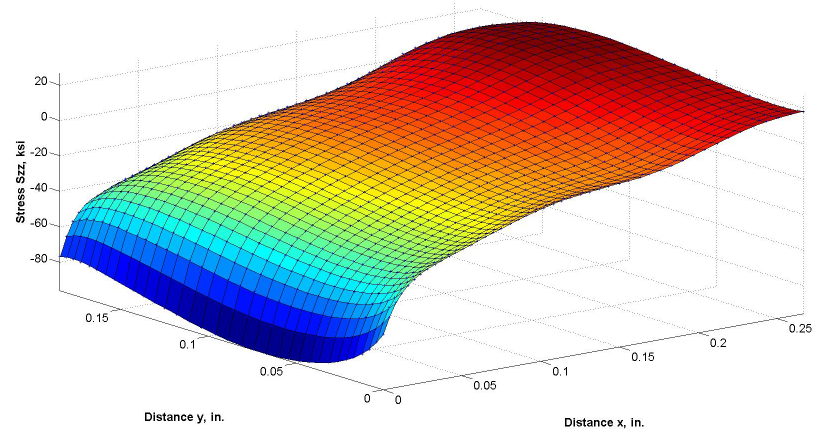


# Study of Variables

- Location of Mandrel Entrance vs. Exit



Correct Residual Stress Orientation

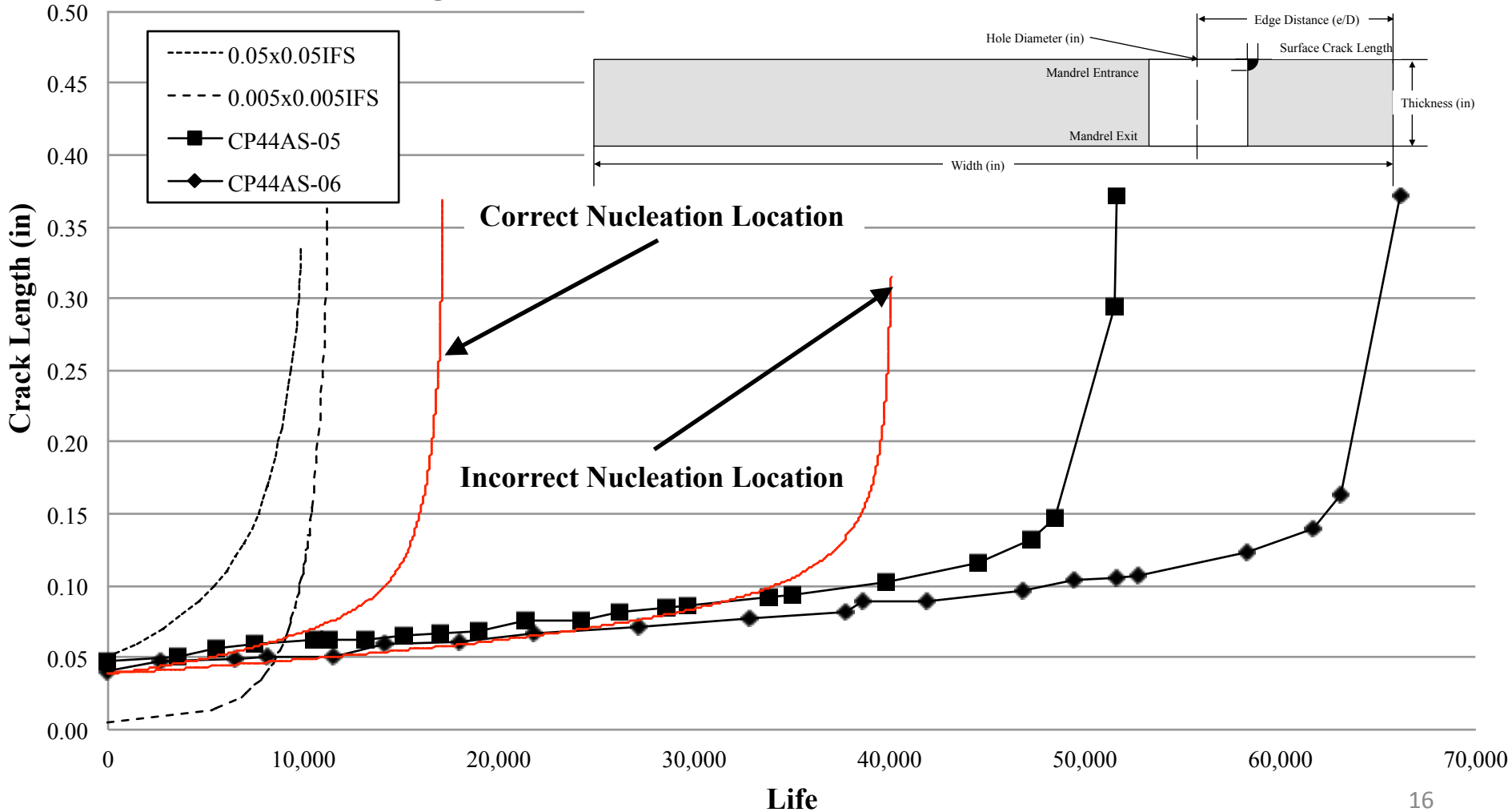


Incorrect Residual Stress Orientation

- Percent Applied Expansion
- 10% Adjustment to RS Field
- Material File
- Percent Growth
- Initial Flaw Sizes

# Orientation of Residual Stress Field

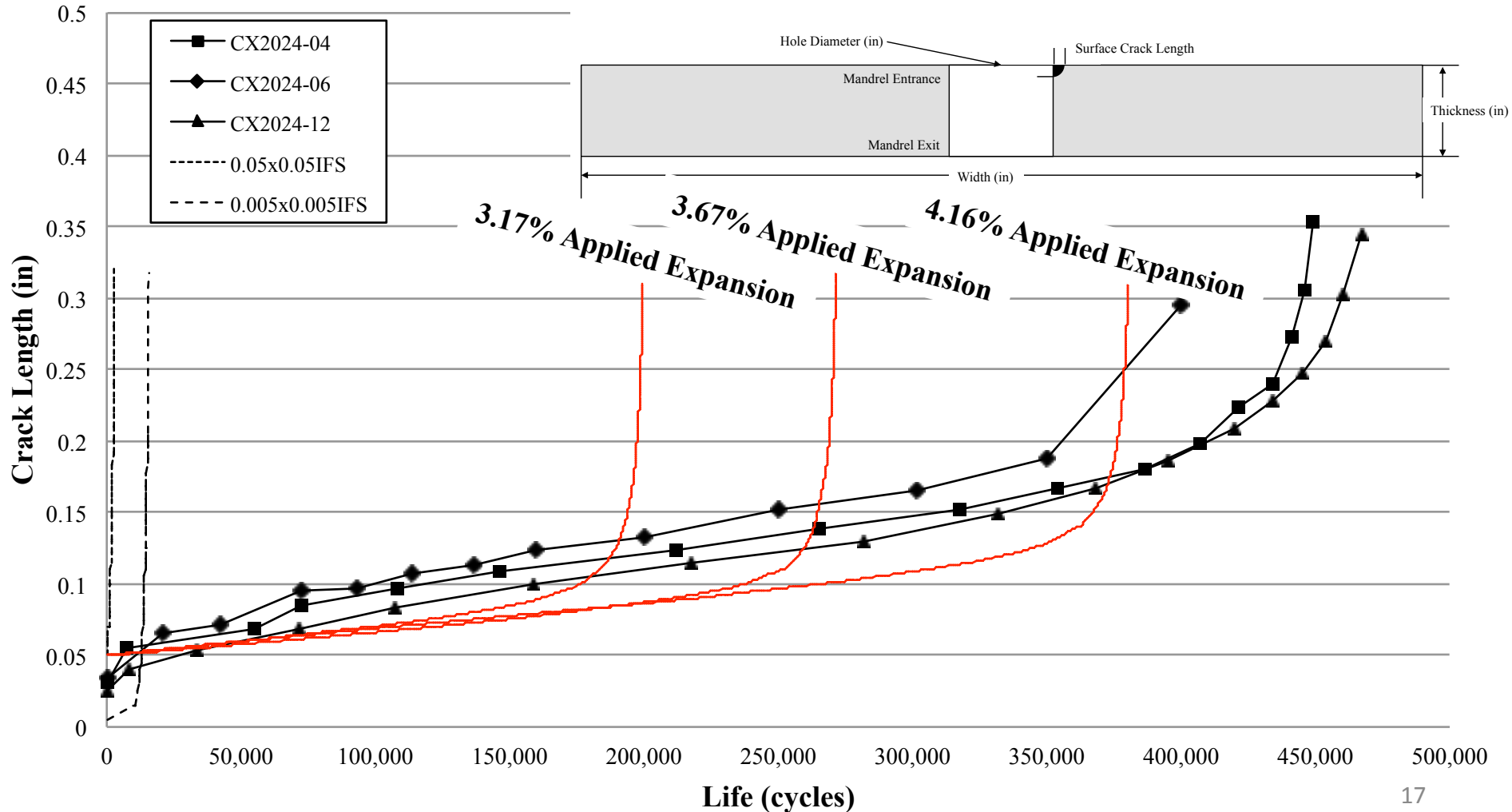
**Fatigue Crack Growth Test Data Showing BAMF Prediction for 1.5 Edge Margin, Variable Amplitude 28ksi Max Stress, Max Applied Expansion Showing Difference in Life Due to Nucleation Location**





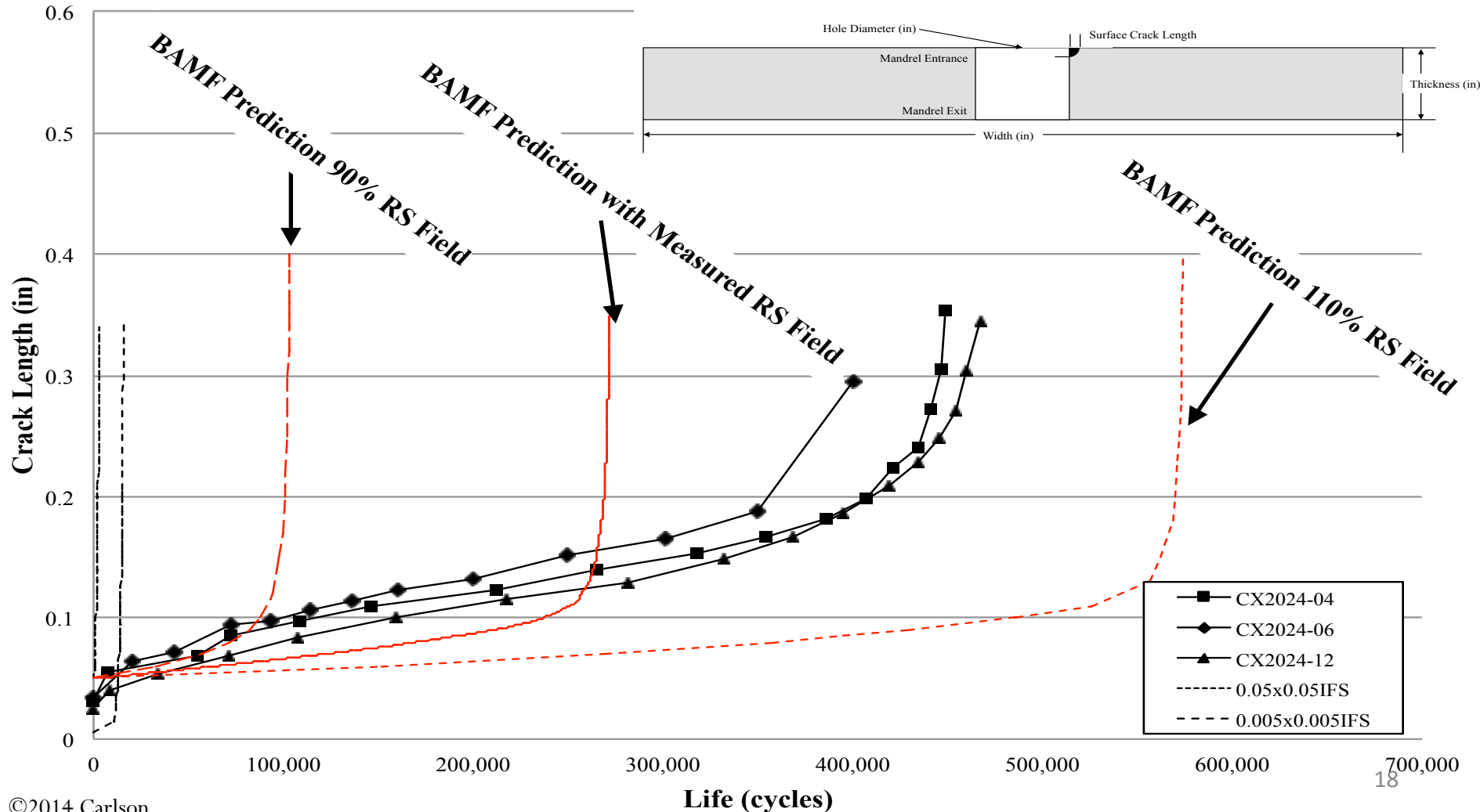
# Percent Applied Expansion

**Fatigue Crack Growth Test Data Showing BAMF Prediction for 4.0 Edge Margin Constant Amplitude 25ksi, R=0.1 3.17%, 3.67% & 4.16% Applied Expansion A-10 Material File, 0.05x0.05in IFS**



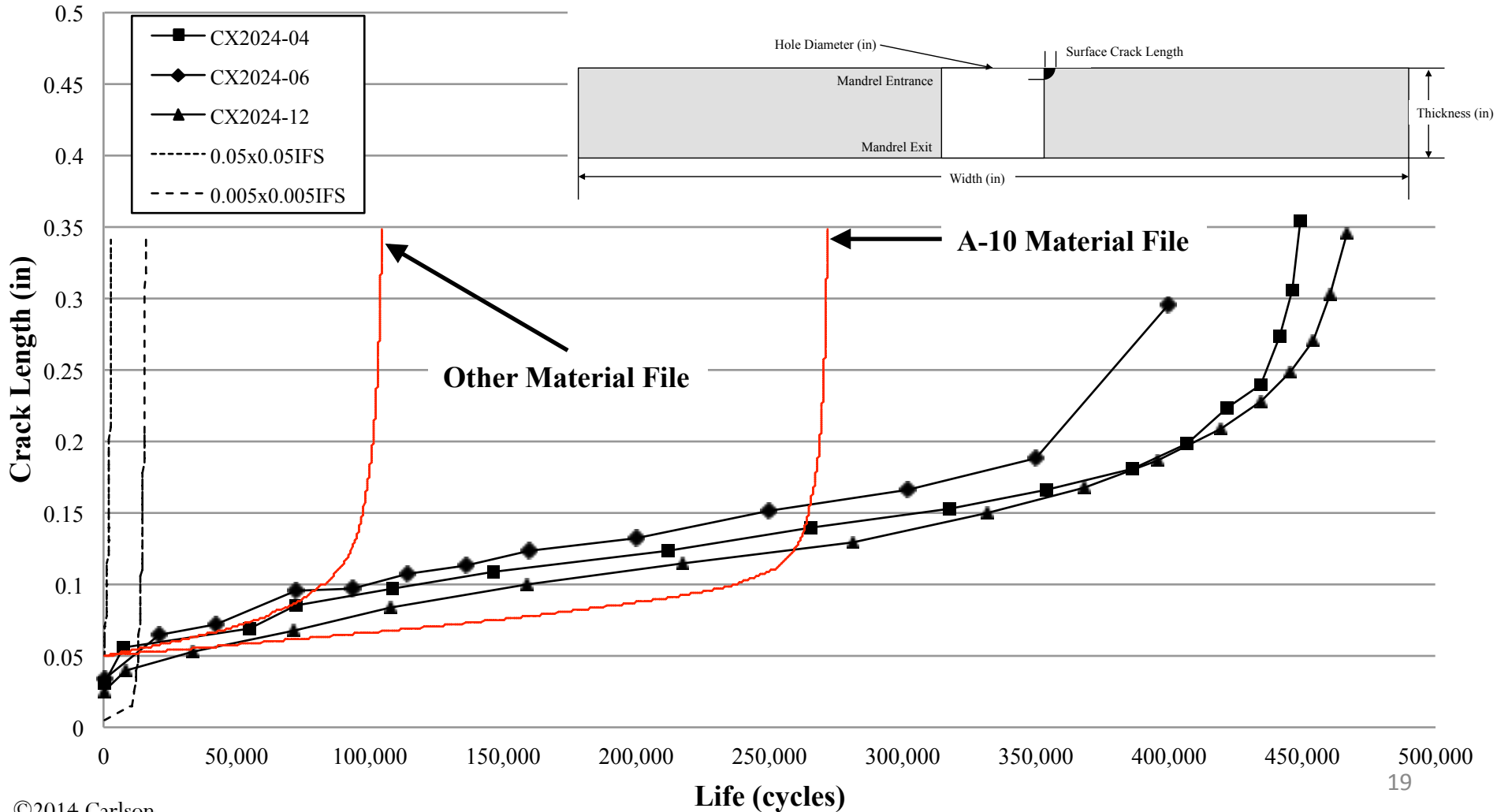
# 90%, 100%, 110% Residual Stress

Fatigue Crack Growth Test Data Showing BAMF Prediction for 4.0 Edge Margin Constant Amplitude 25ksi, R=0.1 Comparing Adjustment to Residual Stress Field for 3.67% Applied Expansion



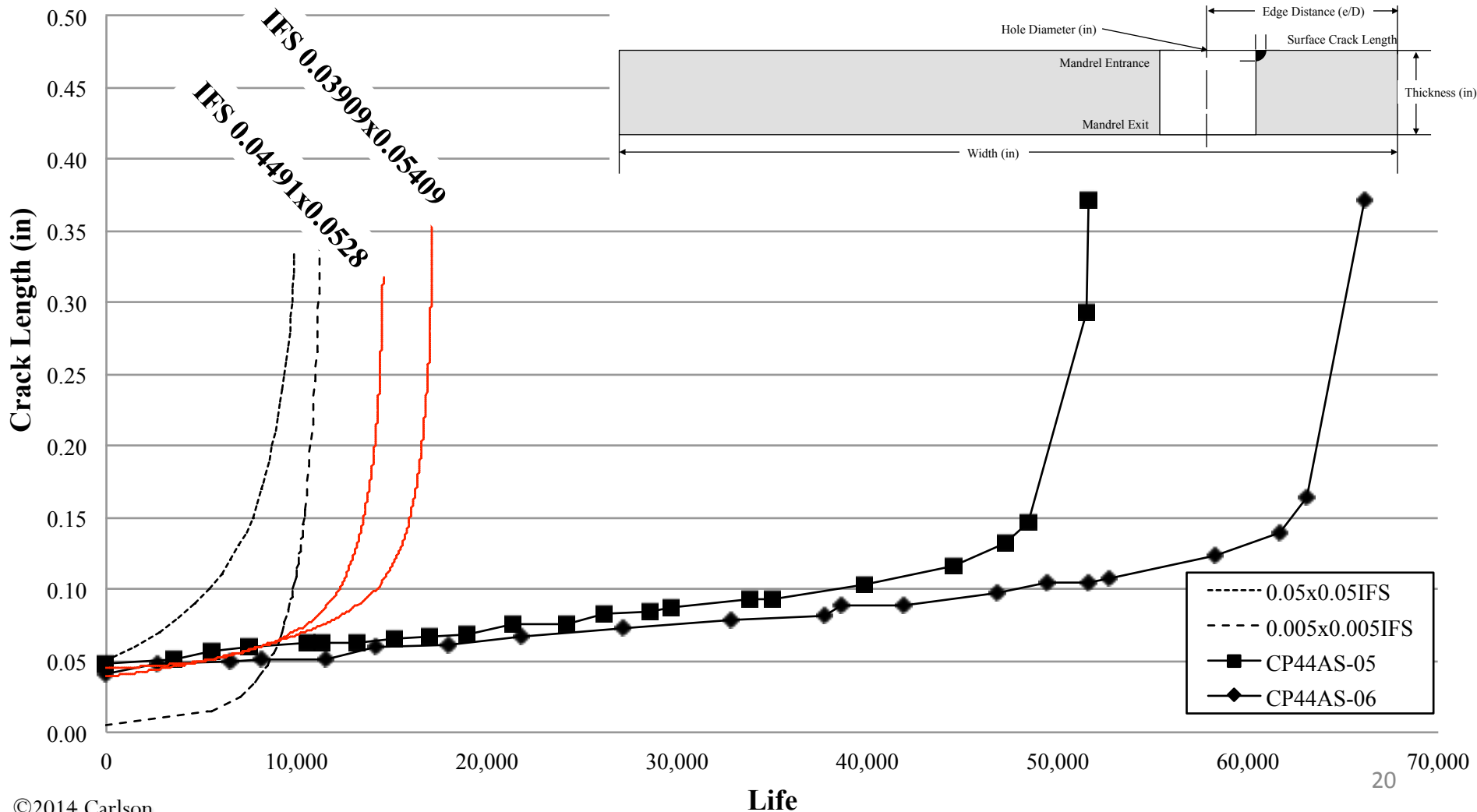
# Material File

**Fatigue Crack Growth Test Data Showing BAMF Prediction for 4.0 Edge Margin Constant Amplitude 25ksi, R=0.1 Comparing Material File Inputs for Same Material**



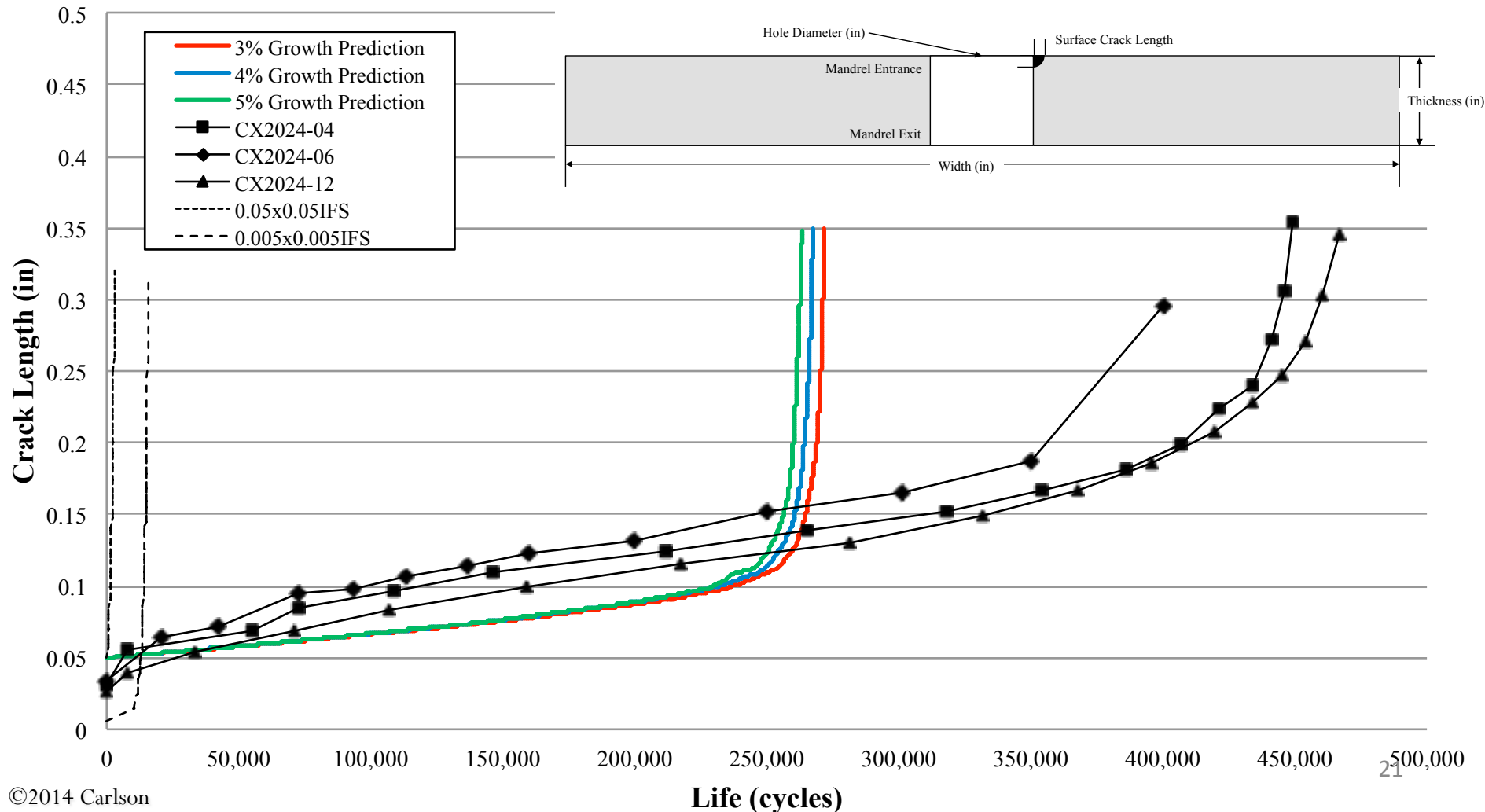
# Initial Flaw Size

## Fatigue Crack Growth Test Data Showing BAMF Prediction for 1.5 Edge Margin, Variable Amplitude 28ksi Max Stress, Max Applied Expansion



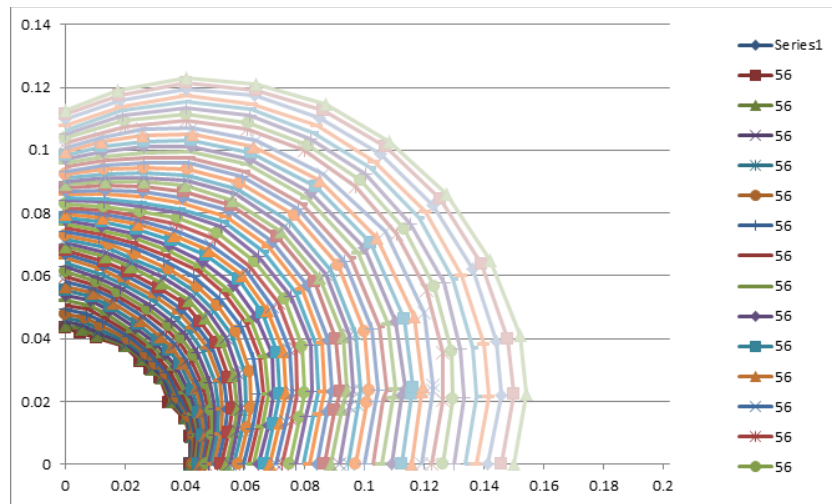
# Percent Growth in AFGROW

**Fatigue Crack Growth Test Data Showing BAMF Prediction for 4.0 Edge Margin Constant Amplitude 25ksi, 3%, 4% and 5% Growth Percentage  
A-10 Material File, 0.05x0.05in IFS**

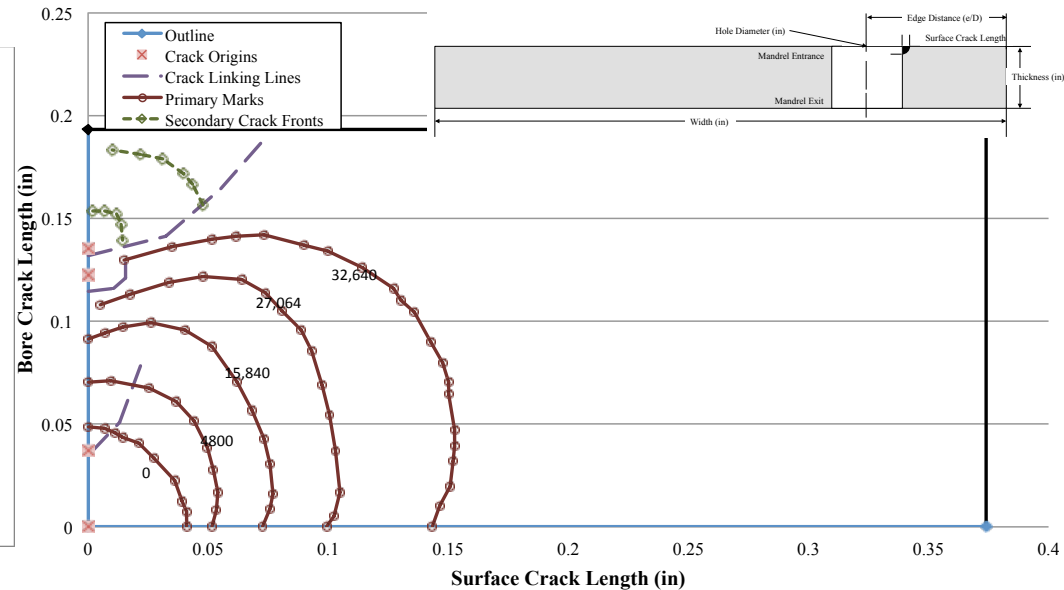


# CP44 SOLR Study

- BAMF Provides Platform for Investigation into SOLR Values
  - Naturally evolved crack shapes match test



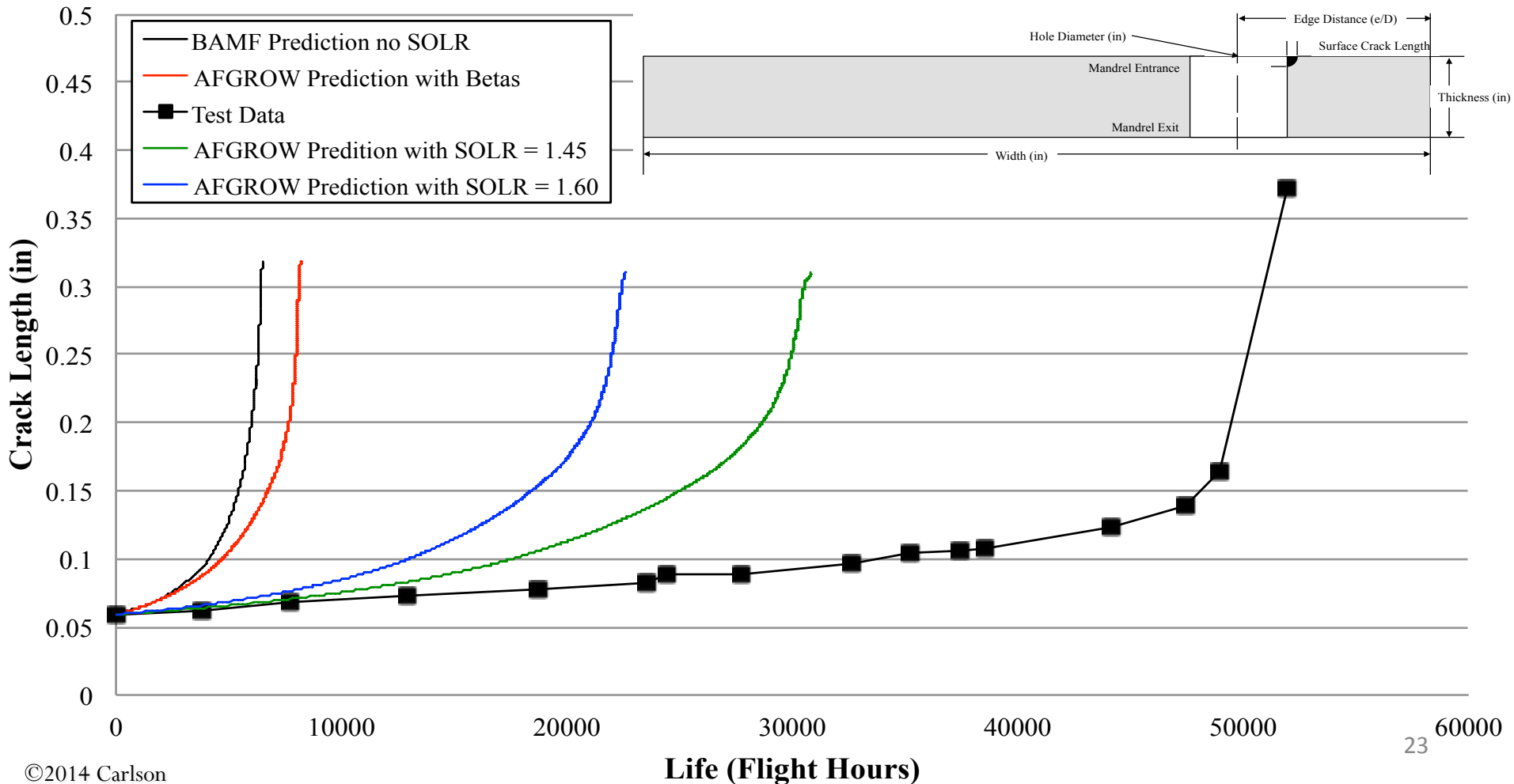
Marker Banding Profile for CP44-09 Dia=0.4375, 1.28 Edge Margin, Max Residual Stress, Max Spectrum Stress = 28ksi



# CP44 Dia. 0.375in Hole

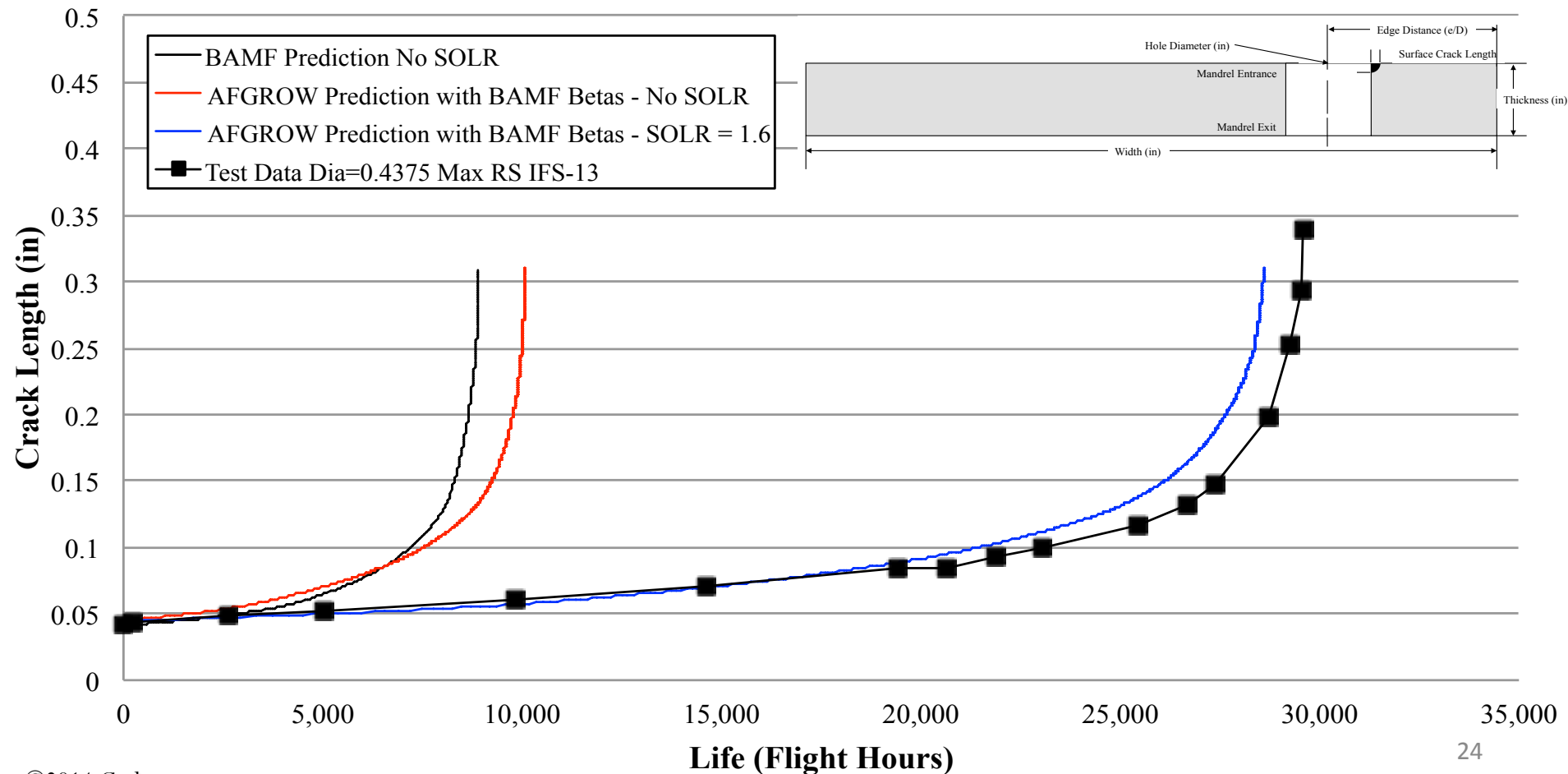
**Fatigue Crack Growth Test Data Showing BAMF Prediction with No SOLR and SOLR Correlation Study for CP44, Max Residual Stress, IFS Normalized, Max Spectrum Stress 28ksi, Dia=0.375 Edge Margin**

**1.5**



# CP44 Dia. 0.4375in Hole

**Fatigue Crack Growth Test Data Showing BAMF Prediction with No SOLR and SOLR Correlation Study for CP44, Max Residual Stress, IFS Normalized, Max Spectrum Stress 28ksi, Dia=0.4375 Edge Margin 1.28**





# Lessons Learned

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- Establish Protocol for Residual Stress Measurements
- Location of Mandrel Entrance vs. Exit
- Additional Research into SOLR for Spectrum Loading
- Still Looking into “Short Crack” Growth Rate Mismatch
- Pay Attention to the DETAILS!!!!!!

# Questions?

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