SMALL FATIGUE CRACK INITIATION AND SIZING USING ACOUSTIC EMISSION

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Outline

- Objectives
- Large crack growth
- Crack initiation and small crack growth
  - Experiments
  - Results
  - Model and validation
- Conclusions

Objectives

- AE-based methodology for small crack detection in SHM applications
- Development of a probabilistic AE-model for in-situ monitoring of small crack growth
- Evaluation of size distribution of initiated crack

AE for Fatigue: Large Crack Growth Rate Model

Acoustic Emission

Amplitude
Energy
Rise time
Counts
Frequency
Waveform

correlation

Fatigue

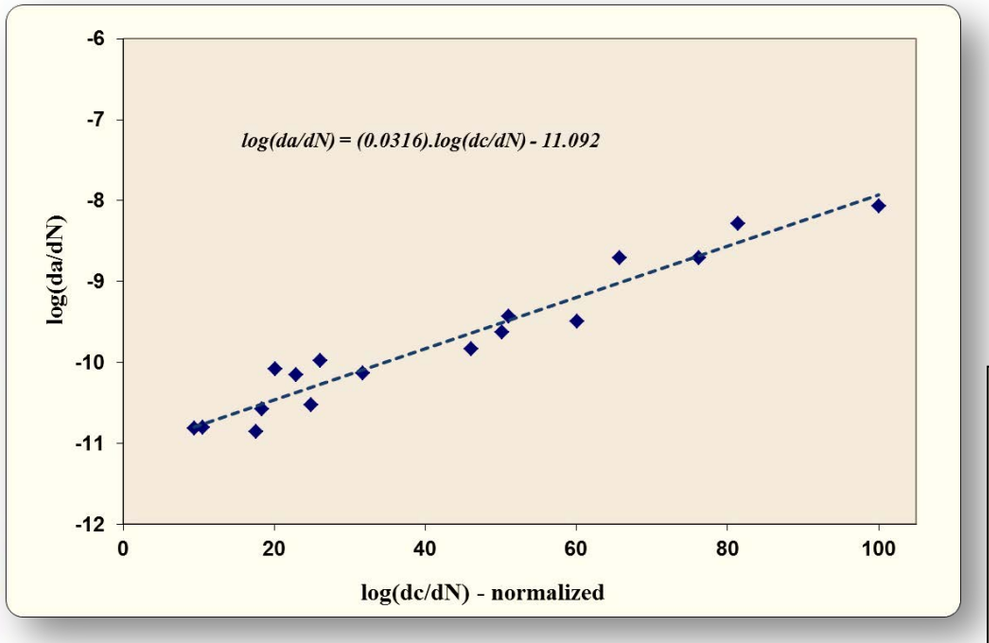
Crack Growth Rate

$\Delta K = f(\text{stress}, \text{crack size})$

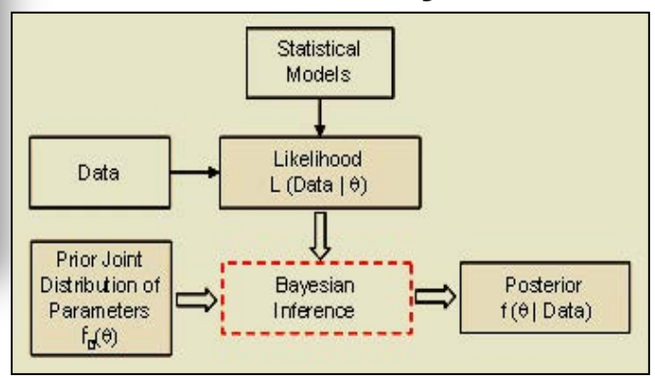
$$\log\left(\frac{da}{dN}\right) = \alpha_1 \log\left(\frac{dc}{dN}\right) + \alpha_2 + \varepsilon$$

$$\varepsilon \approx N(0, \sigma)$$

$$\sigma = \gamma_1 \exp\left(\gamma_2 \frac{dc}{dN}\right)$$



Hierarchical Bayes



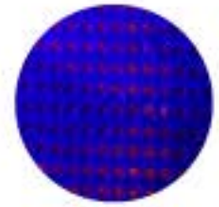
- Standard Compact Tension (CT) specimen
- Al 7075-T6 ,Thickness: 0.125”
- Time-lapse photography
- Image processing software for crack size measurement

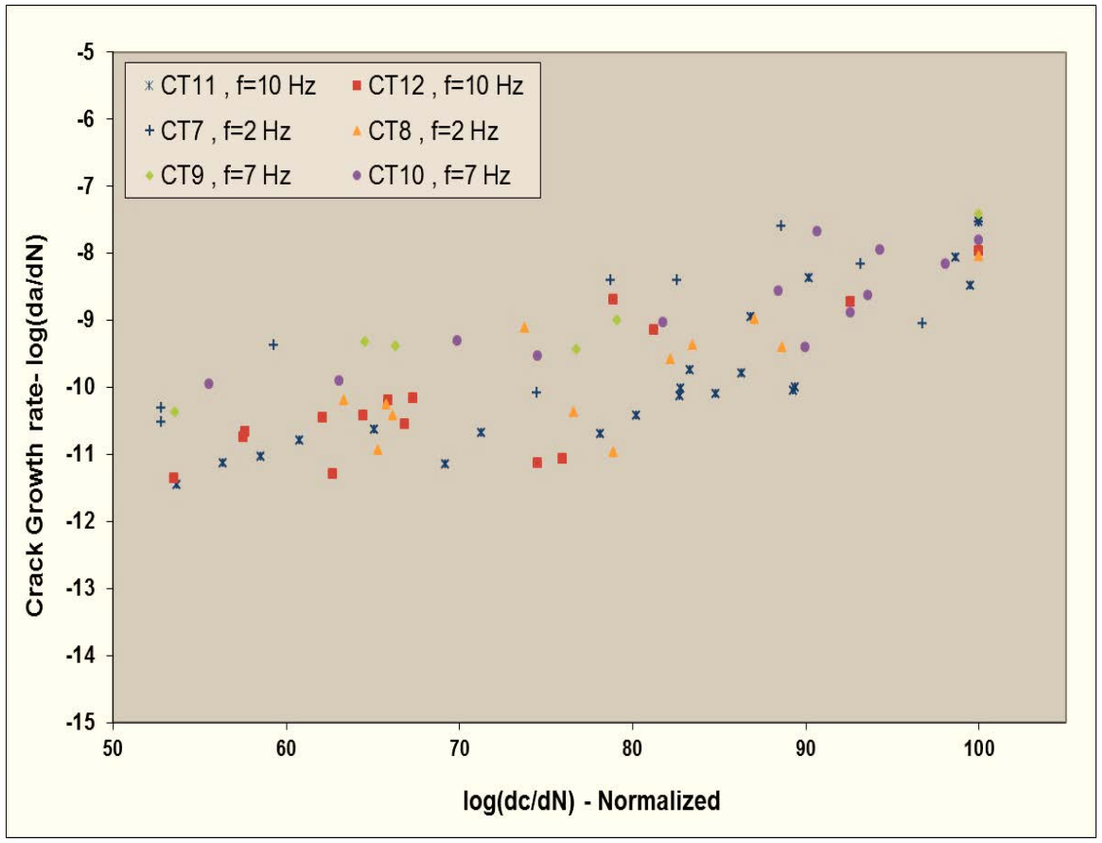
Bassim, M.N., St Lawrence, S. & Liu, C.D., 1994. Detection of the onset of fatigue crack growth in rail steels using acoustic emission. *ENGINEERING FRACTURE MECHANICS*, 47(2), pp.207–214.

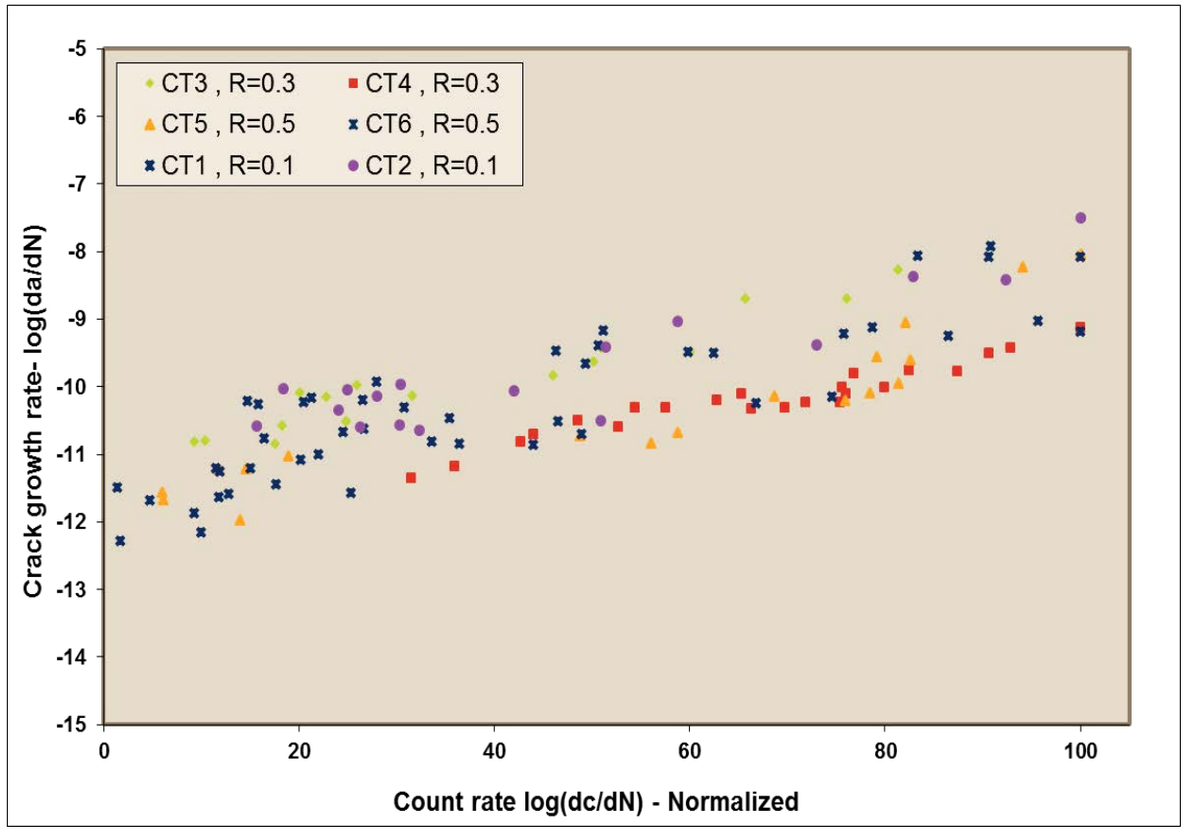
Noise Reduction

- Band-pass filter
  - passes frequencies within (200 kHz – 3 MHz)
- AE Amplitude > 45 dB
- AE events occurring during the loading portion of a cycle
  - Ref.: Morton et al., 1973; Rabiei, 2011; Roberts & Talebzadeh, 2003b
- AE counts occurring close to the peak load
  - within the top 20% of peak load

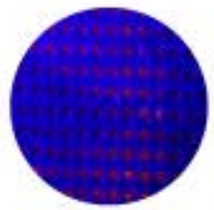
Loading Ratio and Frequency Effects

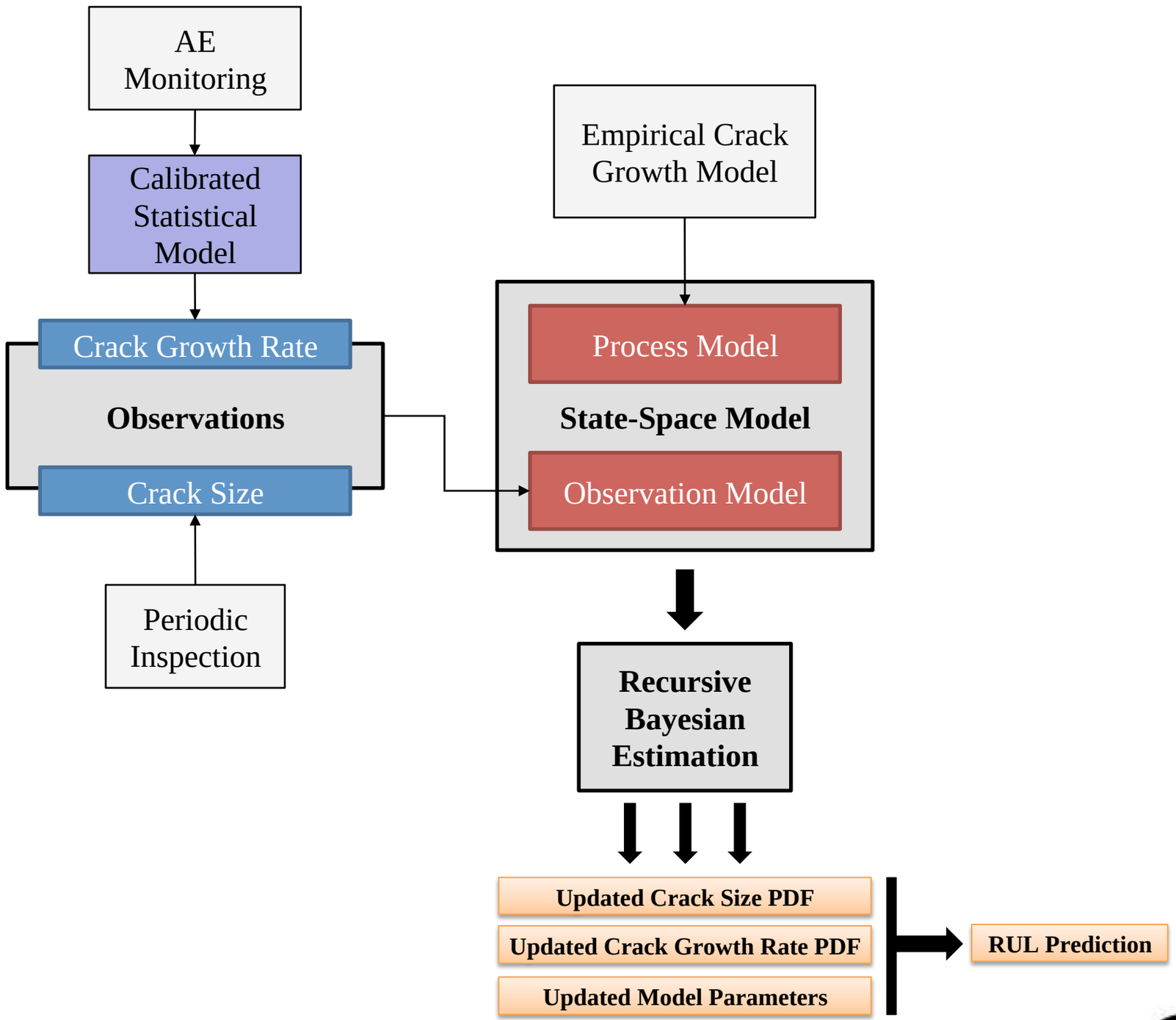






Recursive Bayesian crack length estimation and Model Updating





AE-Based Small Crack Assessment

Crack Initiation Definition

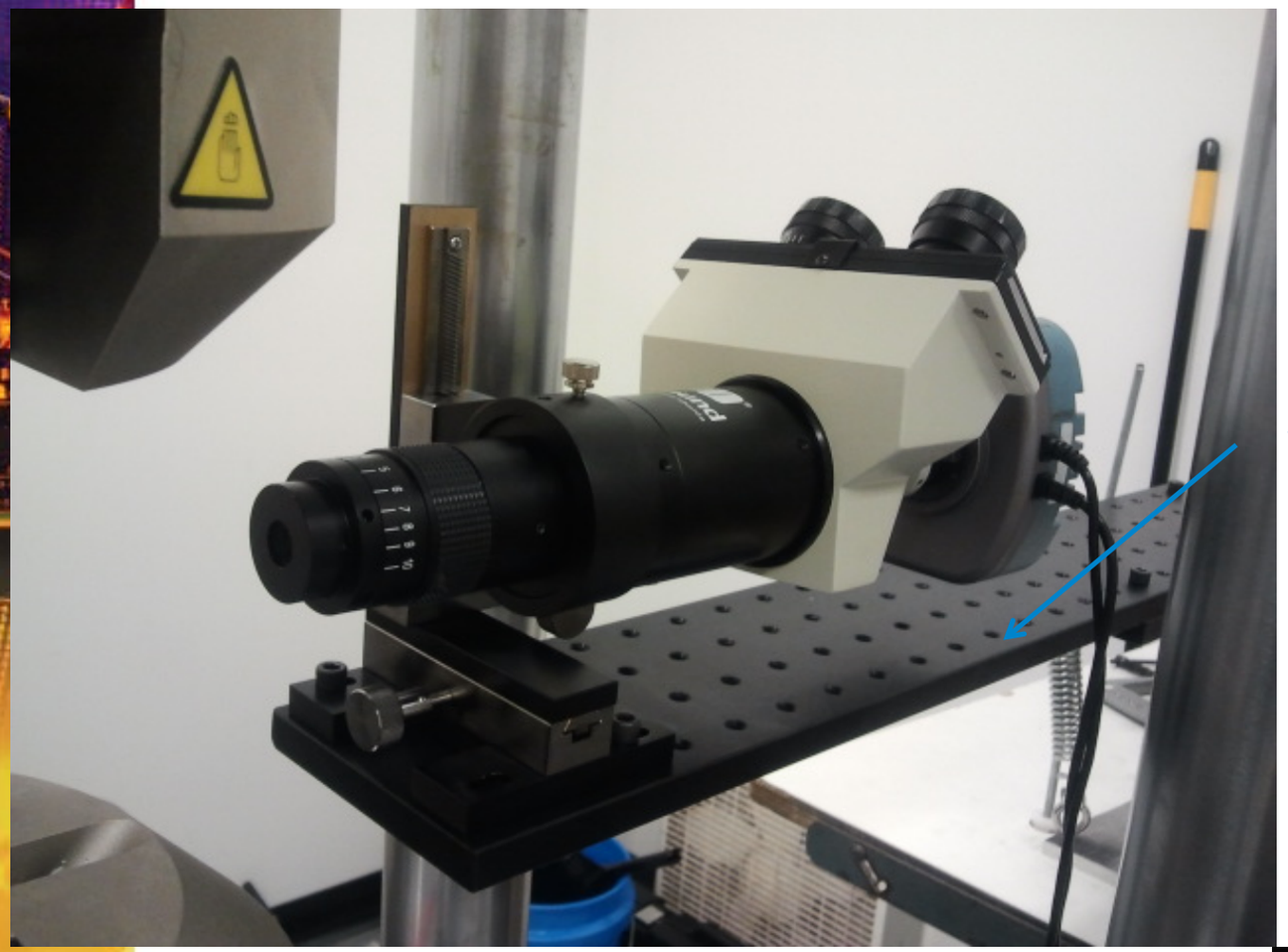
- Subjective definition of crack initiation and small crack
  - fatigue phenomenon
  - arbitrarily specified crack size.

- US Navy crack initiation: 250 μm
  (Iyyer et al., 2007; Papazian et al., 2009)

- Size of grain diameter, depending on material and scale of interest
  (Bhattacharya & Ellingwood, 1998):
  - 51 μm for carbon steel,
  - 120 μm for BS250A53 steel
  - 1 mm for En7A steel

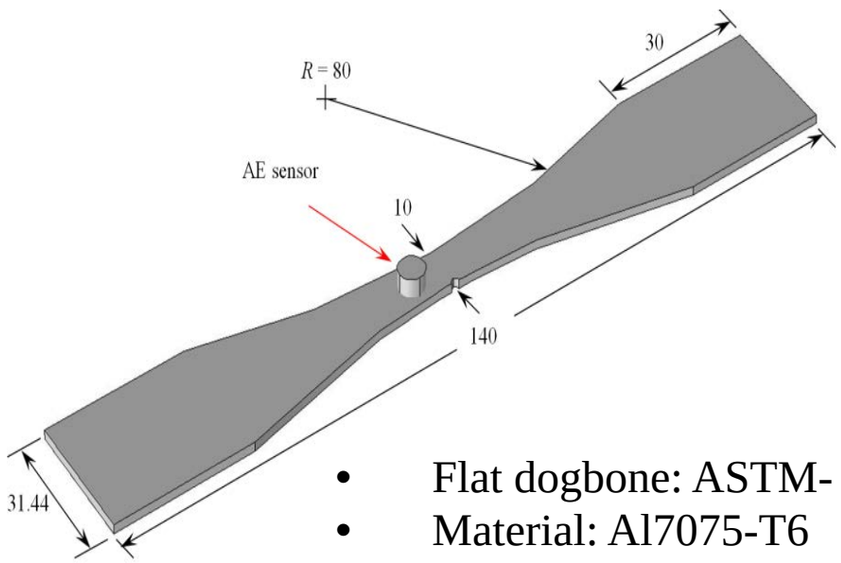
- The crack length of 50 μm was used as the crack initiation
  - grain diameter for Al7075-T6 is in the range: 70-140 μm

Experimental Set up

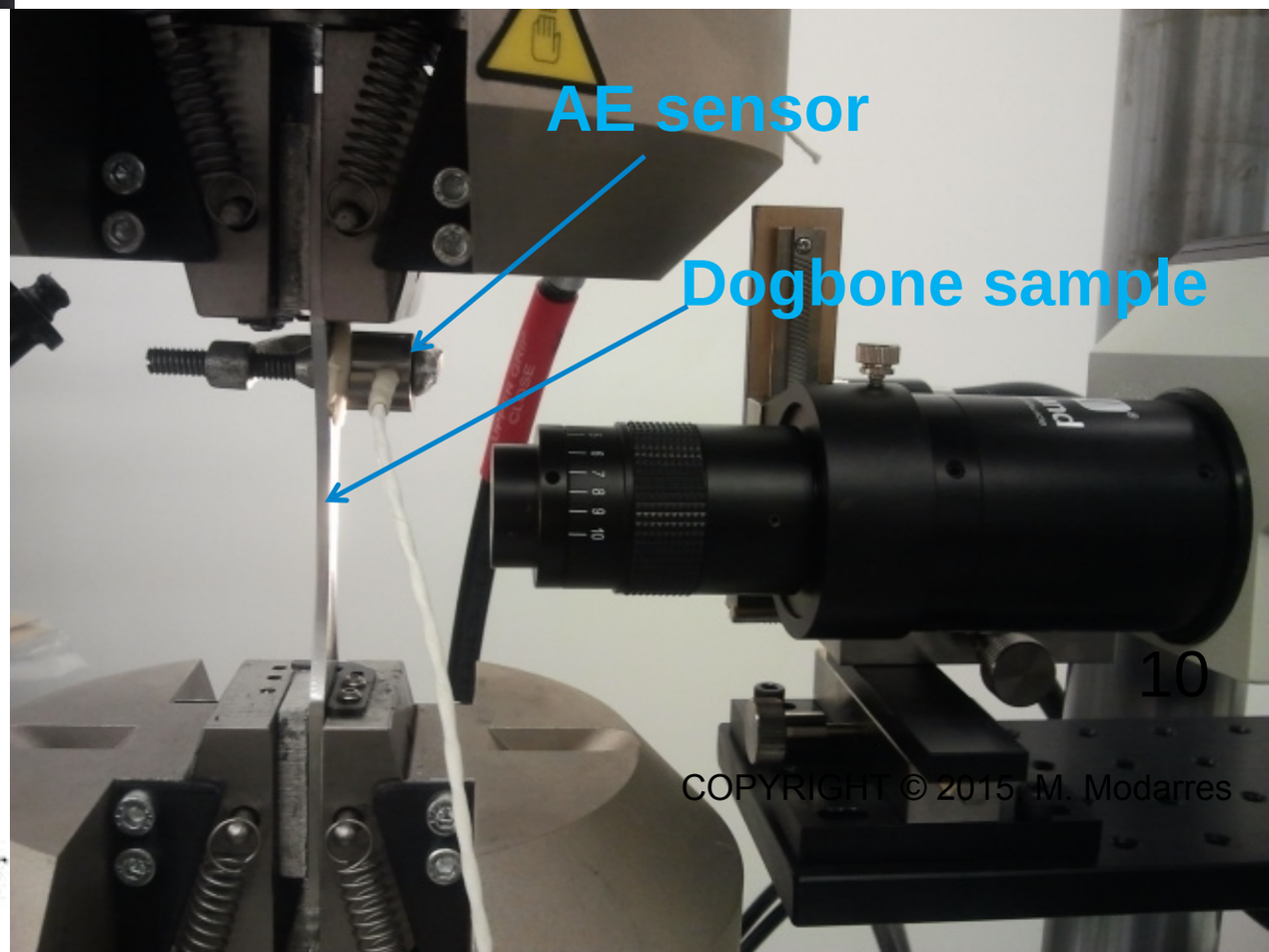


XYZ Positioning Stage

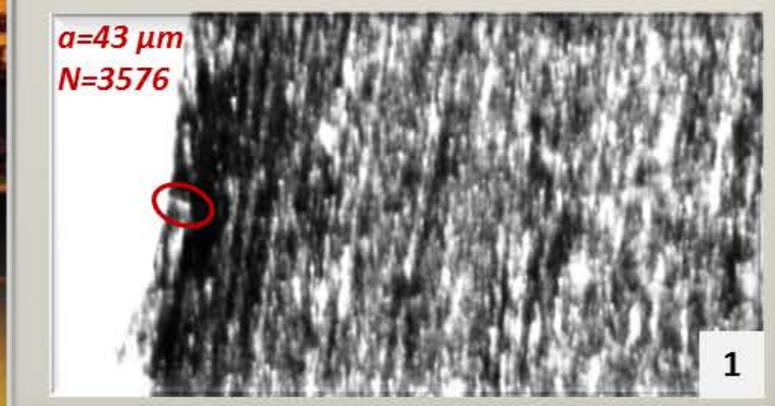
- Optical microscopy to measure small crack length
- uniform cyclic on Al 7075-T6

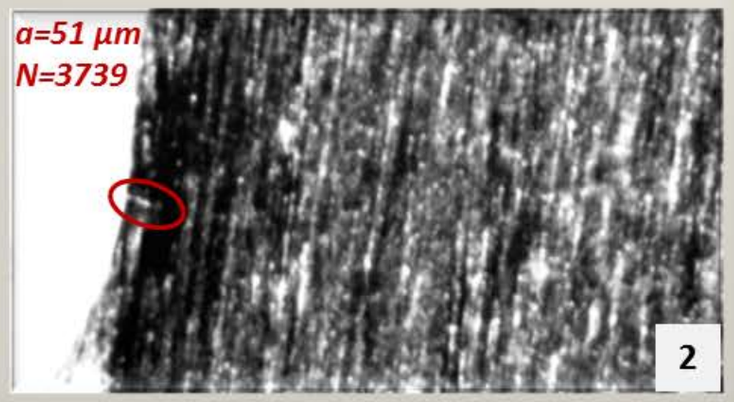


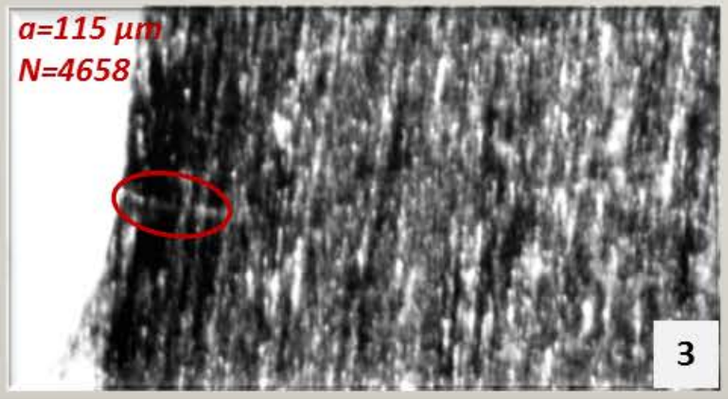
- Flat dogbone: ASTM- E466 − 07
- Material: Al7075-T6
- Dimensions are in **mm**.
- The edge notch**: R=0.5mm**.

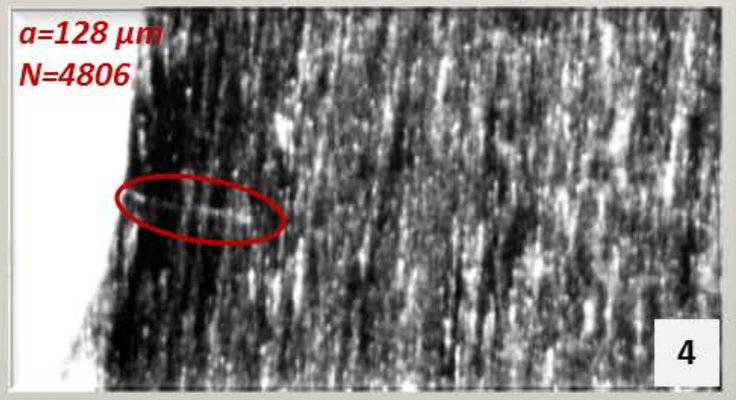


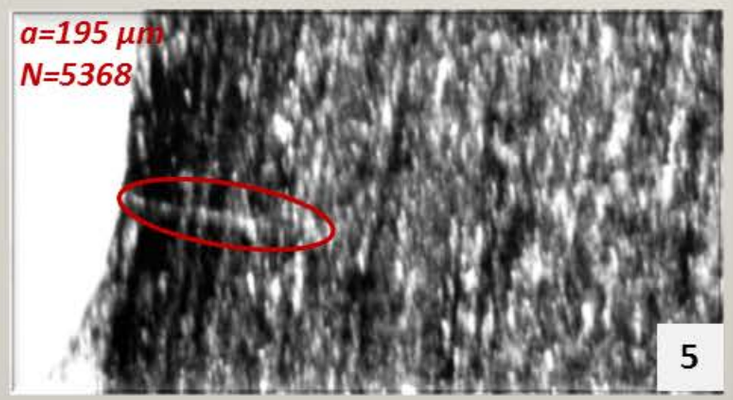
Optical Crack Growth Observation

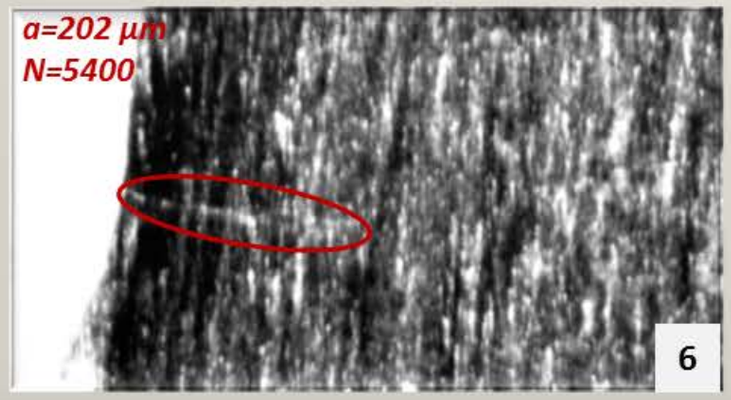


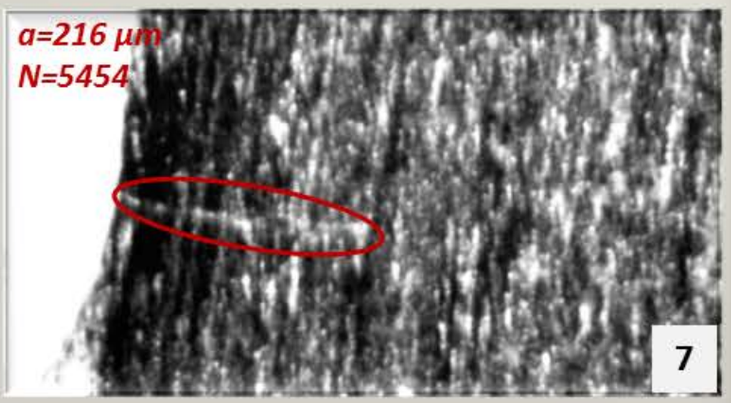


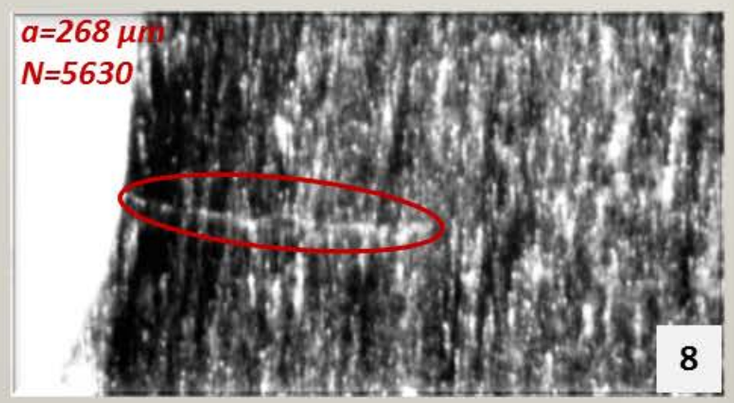


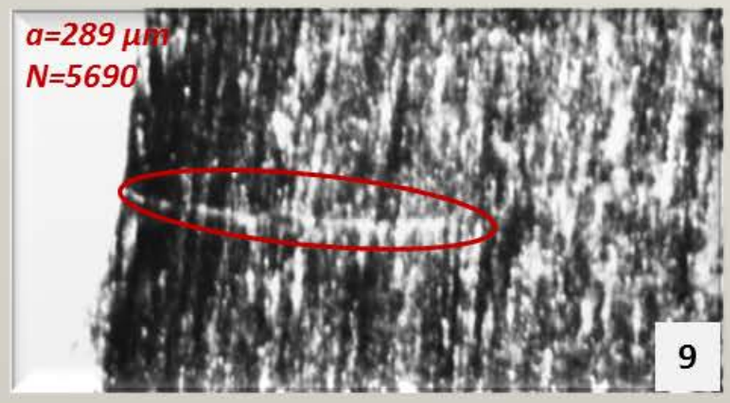




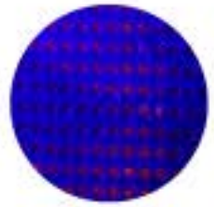


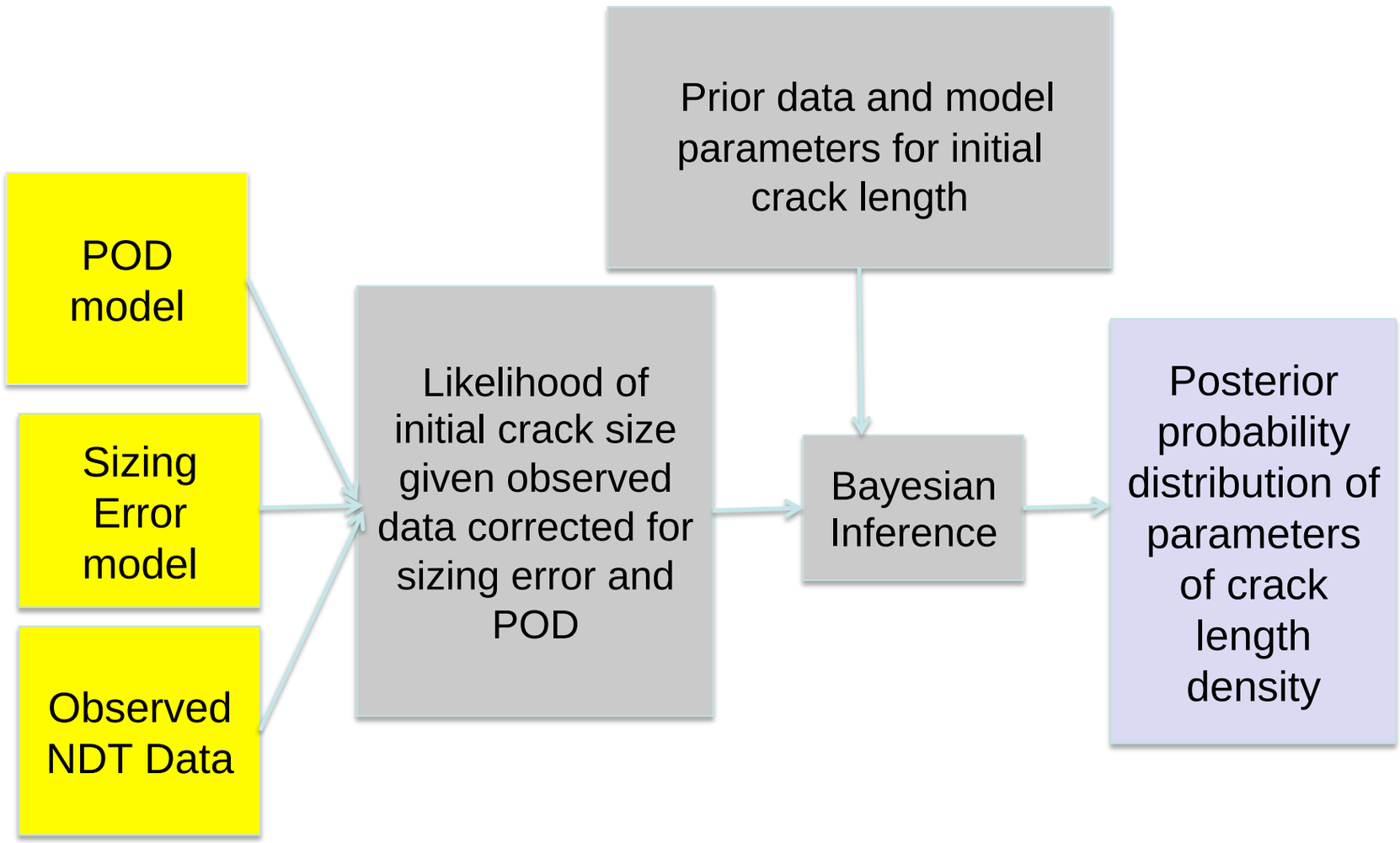




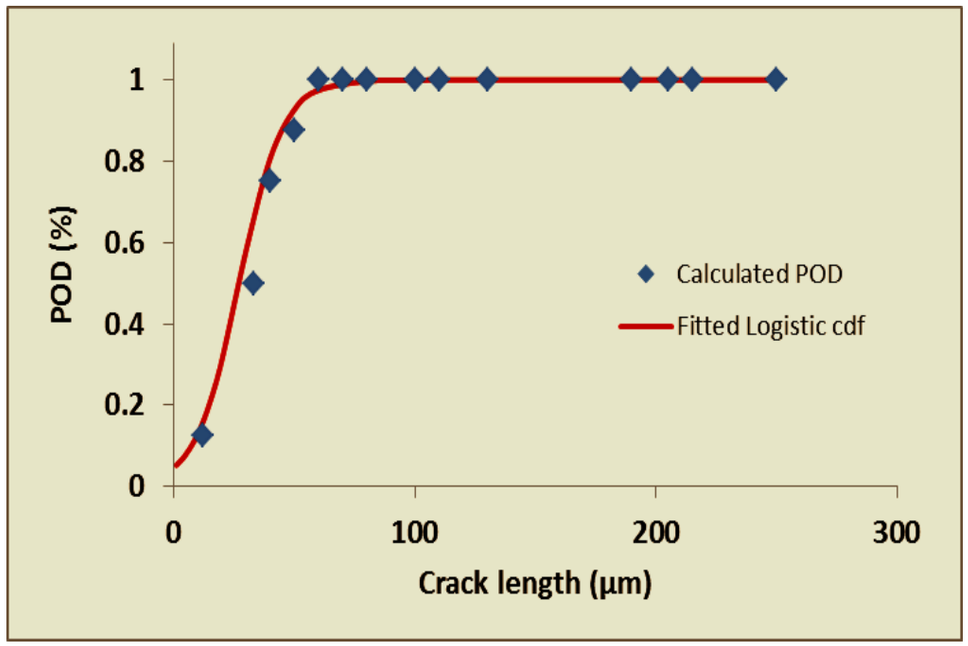


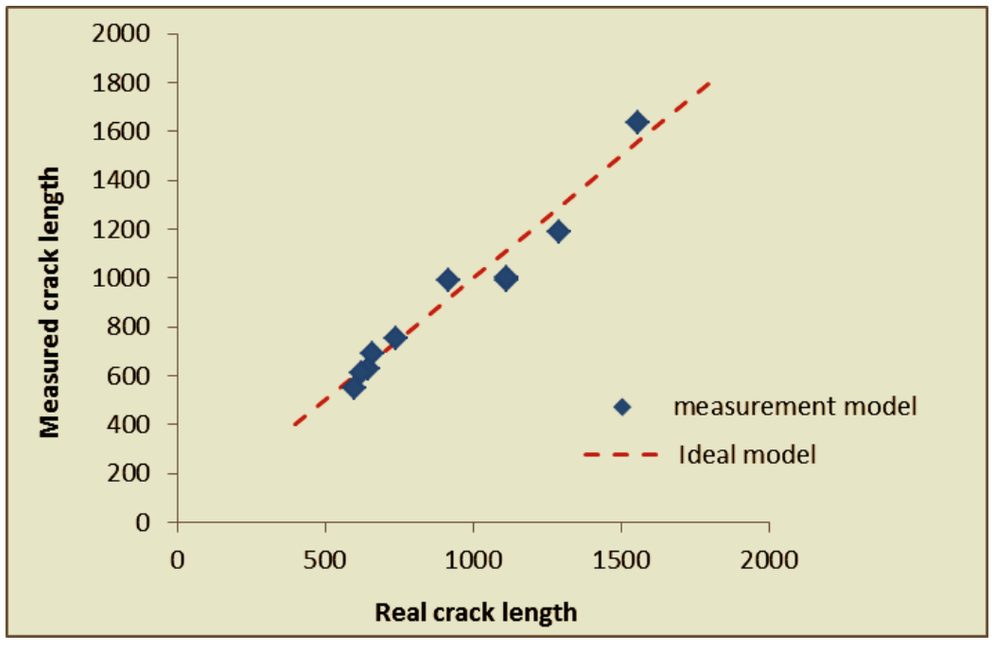
Initial Crack Length Distribution





Accounting for Probability of Detection (POD) & Measurement Error





POD logistic cumulative distribution function:

m≈27 , s≈9

$$F(a,m,s) = \frac{\exp\frac{\pi}{\sqrt{3}}\left[\frac{\log a - m}{s}\right]}{1+\exp\frac{\pi}{\sqrt{3}}\left[\frac{\log a - m}{s}\right]}$$

$$a_e = \beta_0 + \beta_1 a_t + \varepsilon_e$$

$$\varepsilon_e \sim N(0, \sigma_e)$$

Parameter	Estimated value
β_0	-8.59
β_1	0.984
σ_{ME}	*N(9.96, 2.64)*

True Crack Length

$$\frac{a_{t,i}}{a_{m,i}} = F_{m,i}\ ;\ F_m \sim LN(b_m, s_m)$$

$$\frac{a_{e,i}}{a_{m,i}} = \frac{F_{m,i}}{F_{e,i}} = F_{t,i}$$

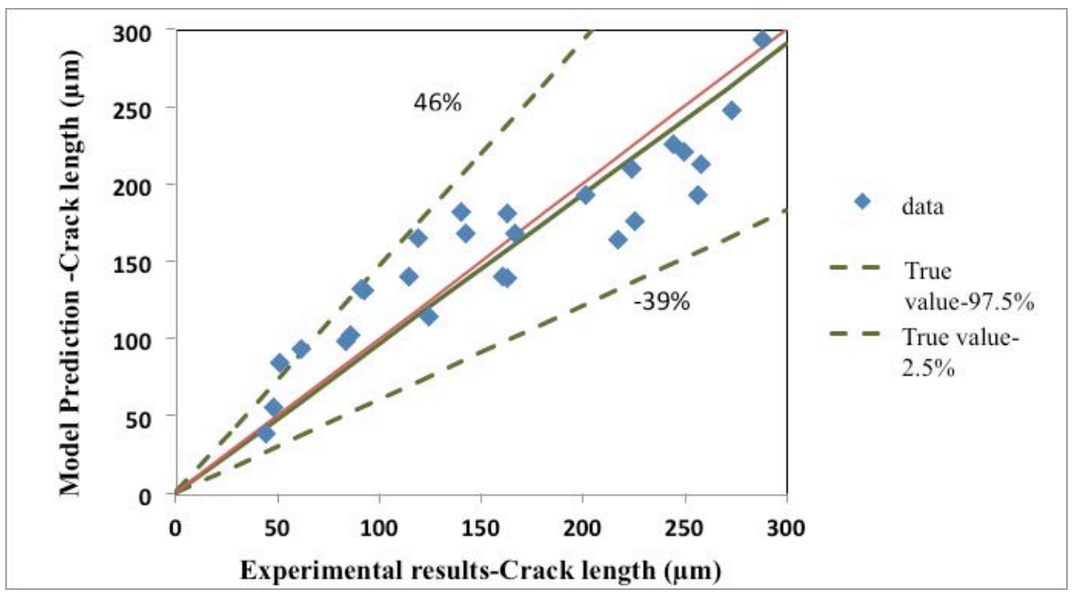
$$L\left(a_{e,i}/a_{m,i}, b_e, s_e \middle| b_m, s_m, m, s\right)$$

$$= \prod_{i=1}^{n} \left(\left(POD\left(a_{e,i}|m,s\right)\right) \left(\frac{1}{\sqrt{2\pi}\left(\frac{a_{e,i}}{a_{m,i}}\right)\sqrt{s_m^2 + s_e^2}} \right) exp\left(\frac{-\left[ln\left(\frac{a_{e,i}}{a_{m,i}}\right) - (b_m - b_e)\right]^2}{2(s_m^2 + s_e^2)} \right) \right)$$

$$a_t \sim LN(ln(a_m) + b_m\ , s_m)$$

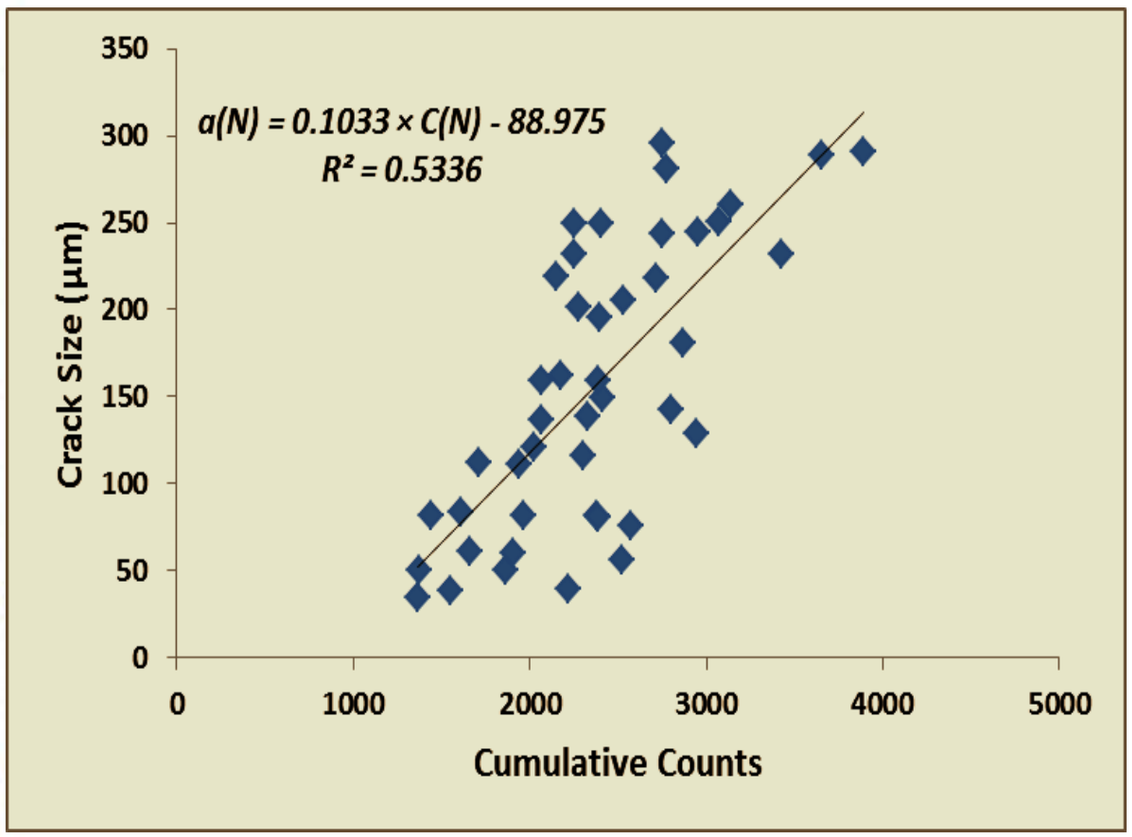
$$a(N) = \alpha \cdot I(N) + \beta$$

I(N)= AE Index: Count, Intensity, Entropy



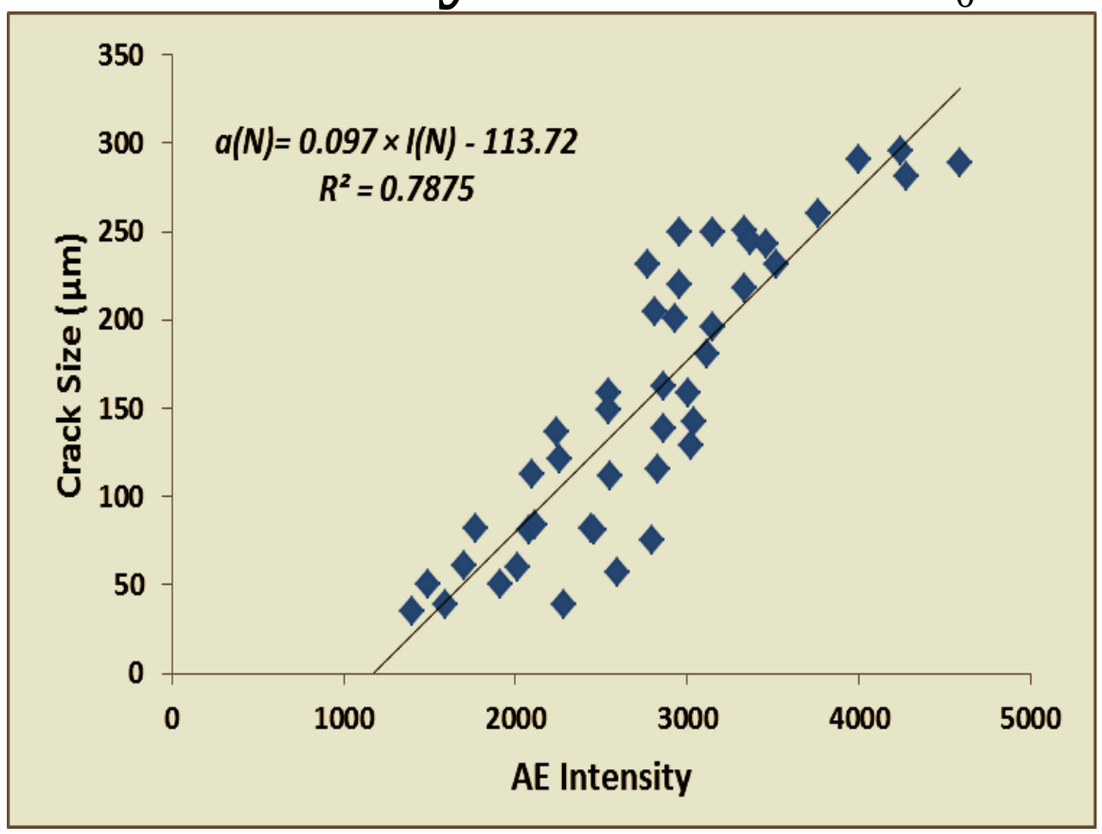
Examples of Small Crack Growth Vs. AE Features

AE Counts



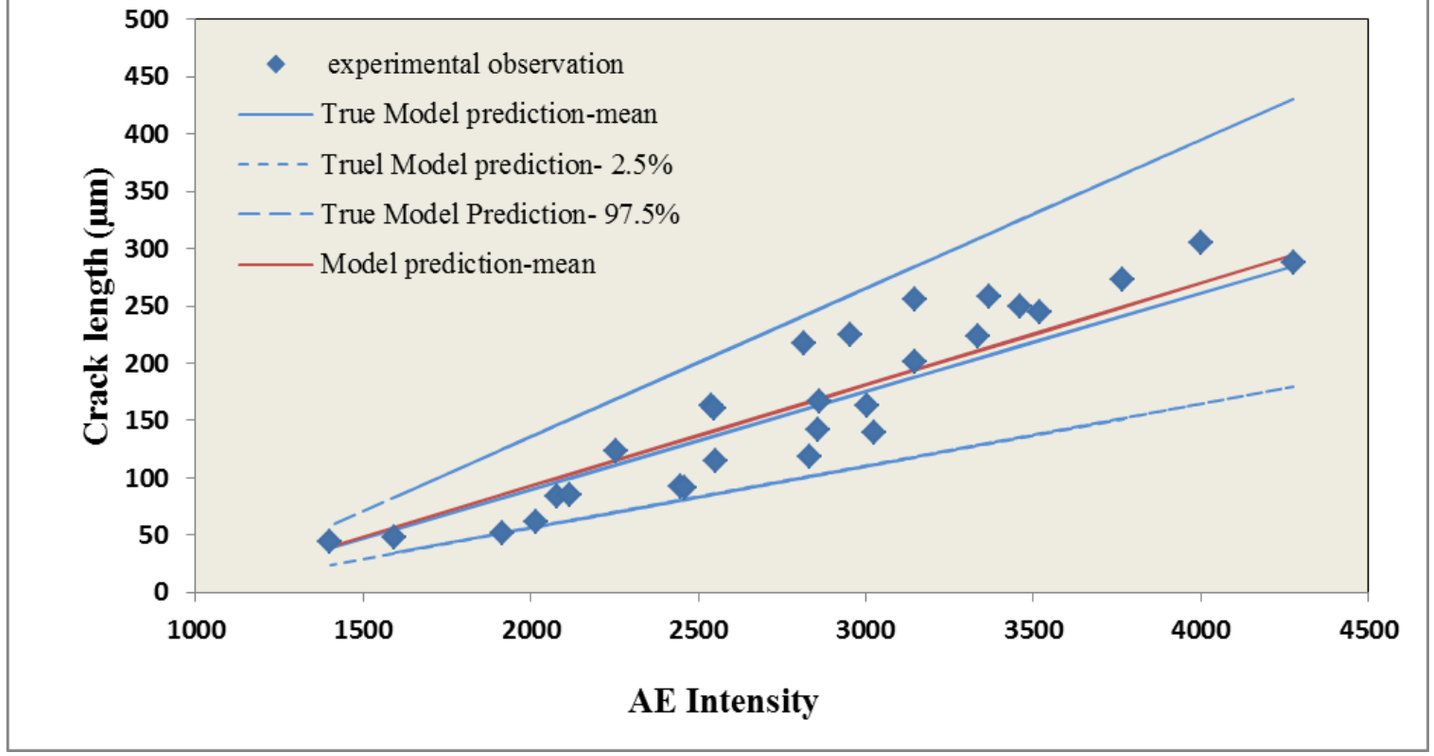
AE Intensity

$$I(t) = C(t) \times \frac{A(t)}{A_0}$$



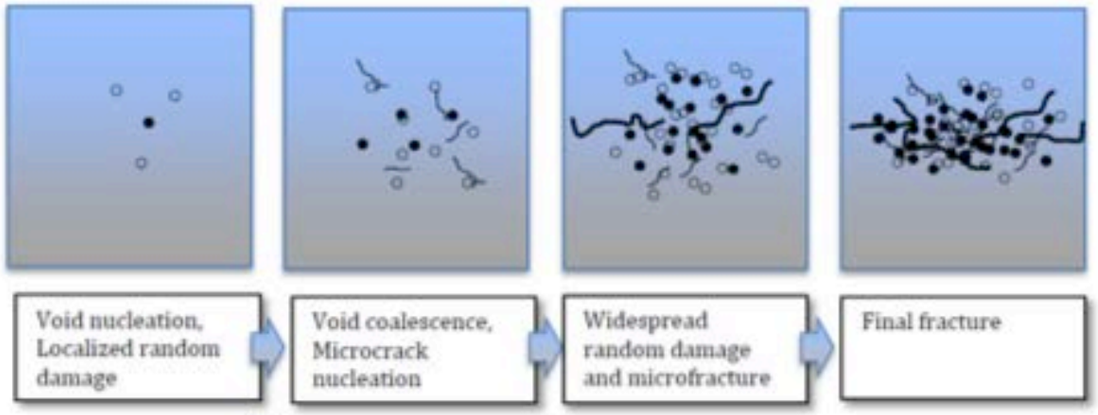
- AE Amplitude correction factor A(t)
- A_0 = 35 dB

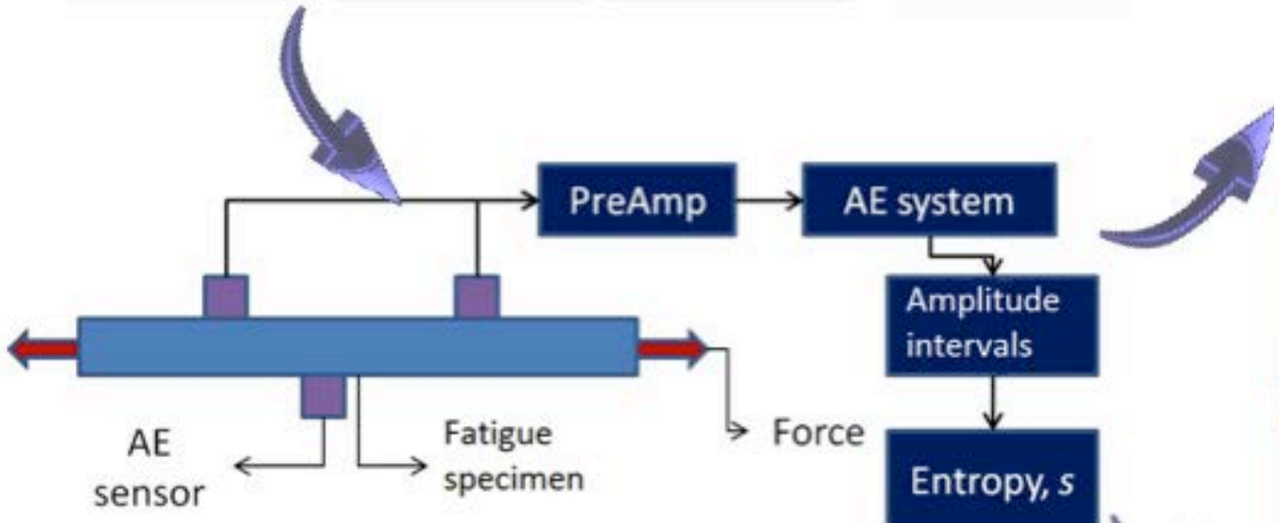
Model Prediction

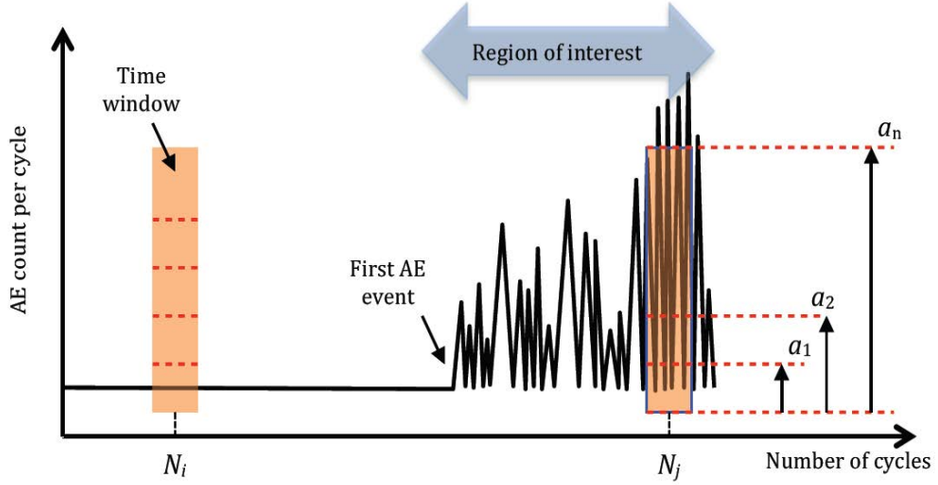


Posterior predictive model with the uncertainty bounds

New Directions: Information Entropy of AE







Divide signals into n amplitude intervals:

$a_i \quad i=1,2,\ldots,n$

Define x_i as:

x_i = detected acoustic signals at interval a_i

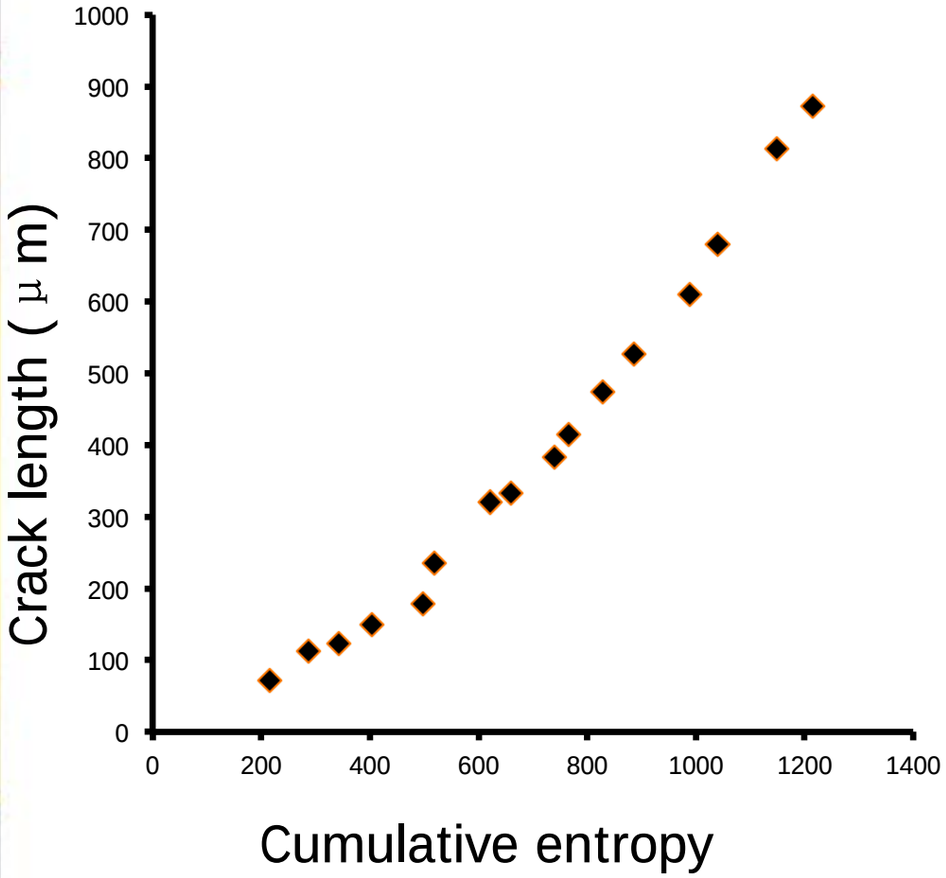
Probability of detecting signals with amplitude a_i:

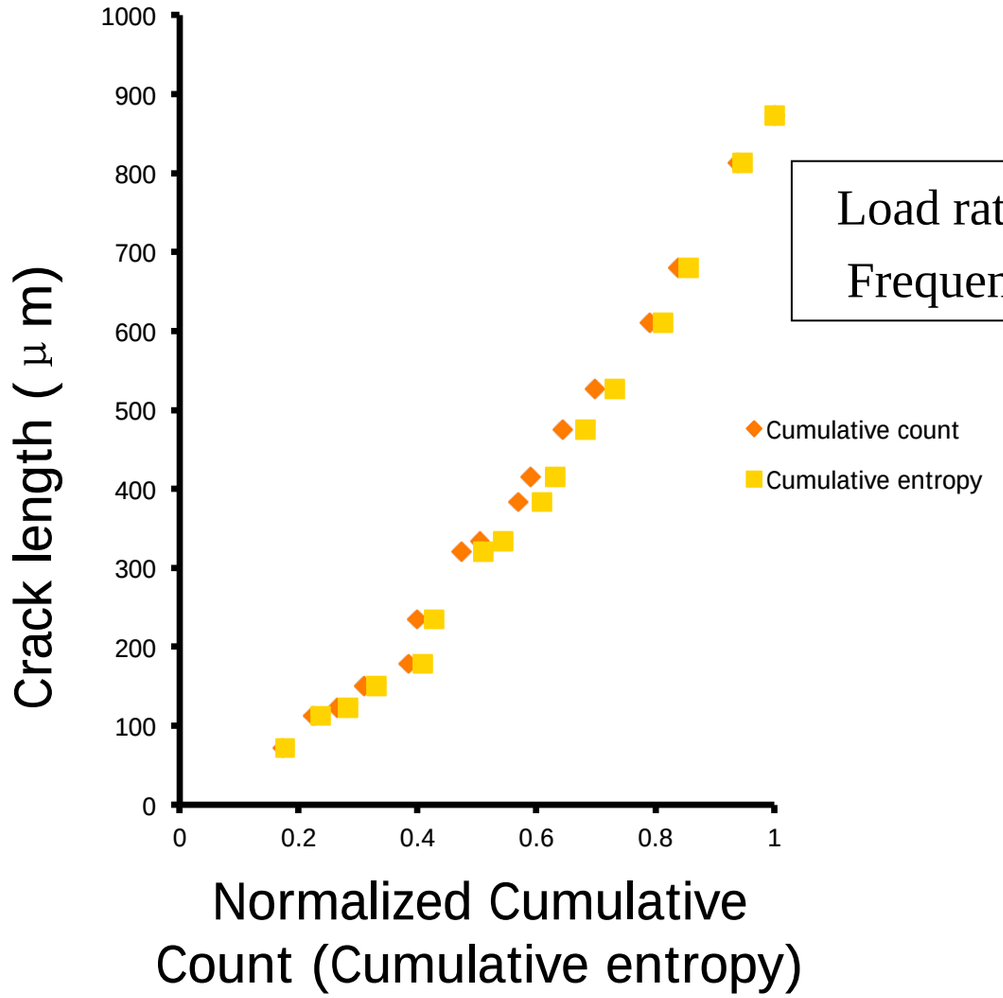
$$p_i = \frac{x_i}{\sum_1^n x_i}$$

Entropy of the signal, S:

$$S = -\sum_1^n p_i \ln p_i$$

AE entropy vs. AE count





Conclusions

- Large crack growth and crack length sizing probabilistic model
- Crack initiation at 50 μm using AE features
- Small crack growth and sizing using various AE features
- Varied materials, geometries and AE features tested
- Tests are underway for subsurface pre-initiation detection

Thank you

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