Some Recent Progress in Modeling Crack Growth in Residual Stress Fields

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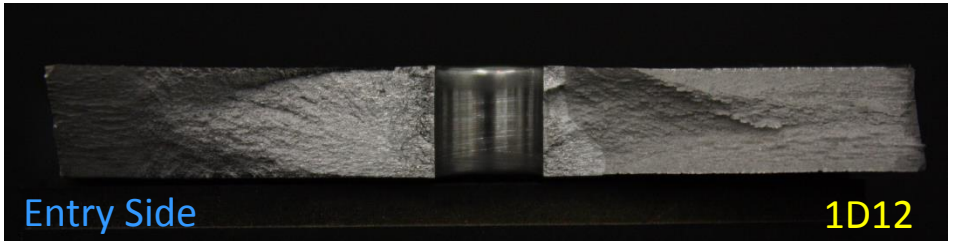
AFGROW Workshop Layton, Utah 2014

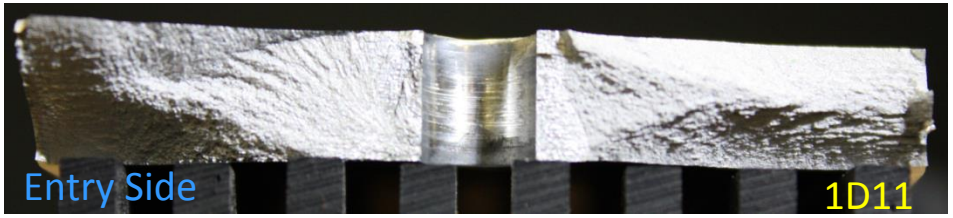
Agenda

- Background
- Improvements to StressCheck (CIM→CIM-LC)
- Verification of CIM-LC
- Validation
  - AFGROW Computed Kres
  - StressCheck Computed Kres
  - BAMF (A-10)
  - CPAT (ESRD)
- Conclusions

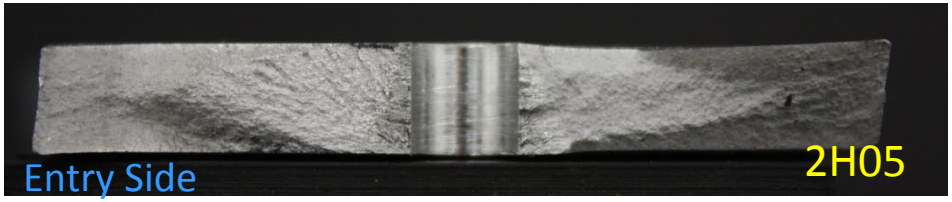
“P-shape” “Idaho” Fracture Face Surface



7075-T6

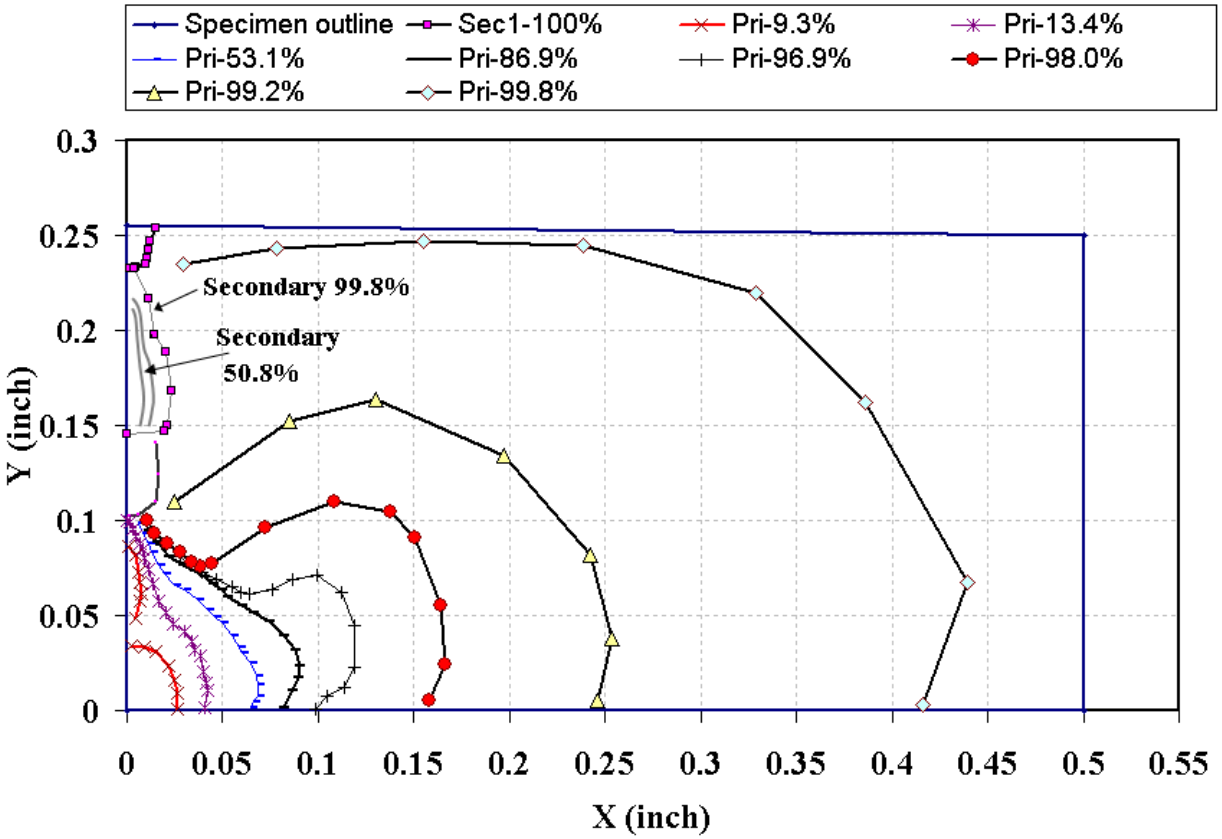


7075-T6

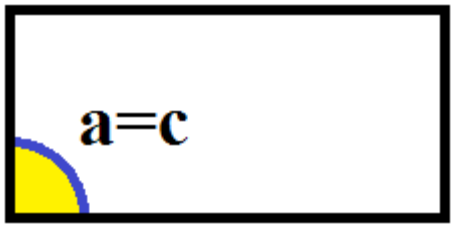
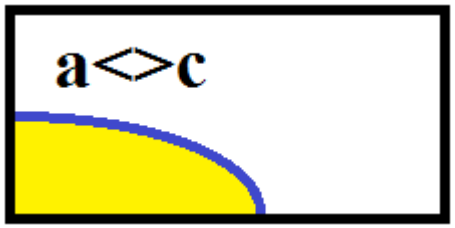


2024-T3

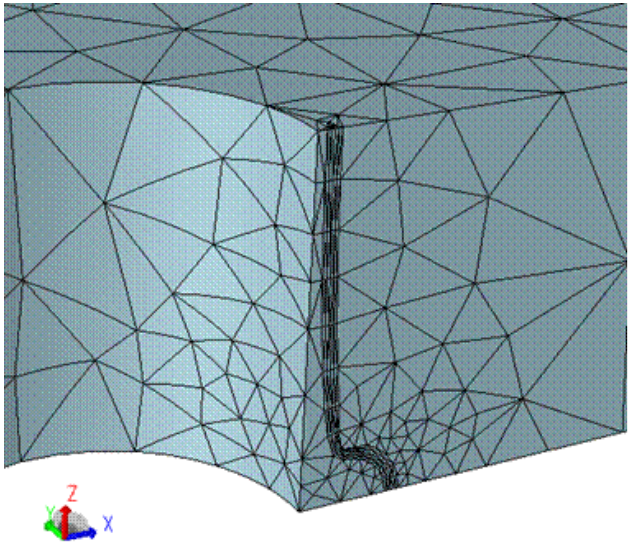
Crack Propagation through a Complex Cold Work R/S Field

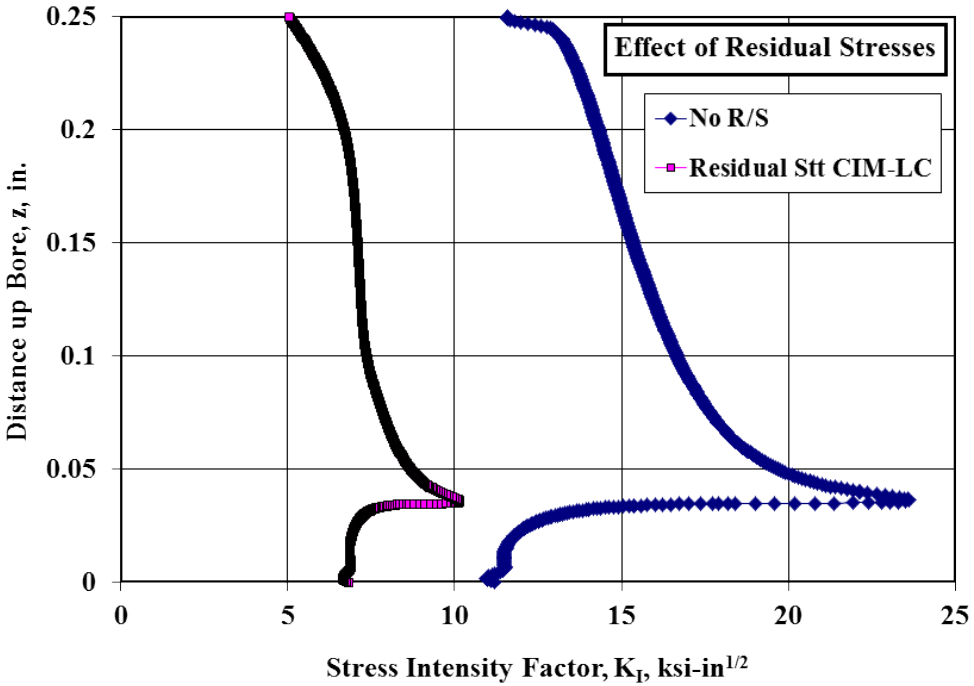


Sources of Model Deficiencies

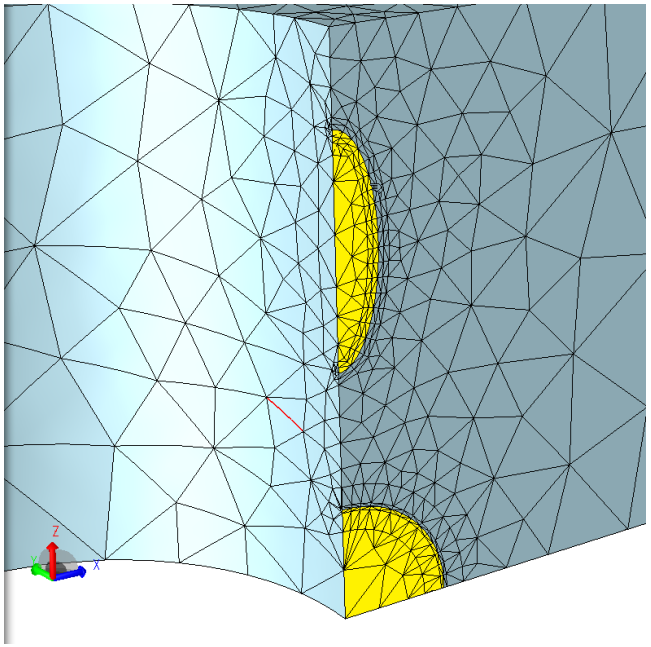
ID	Model	Reality
1		
2	Co-planar cracks	Non co-planar cracks
3	Linear Elastic Fracture Mechanics (Linear superposition)	Elastic-Plastic Fracture Mechanics
4		
5	Residual stress not time or load dependent (fixed)	Residual stress time or load dependent (not fixed)
6	**Single crack**	**Multiple cracks**
7	Residual stress measured with contour method	Stresses may not be responding elastically

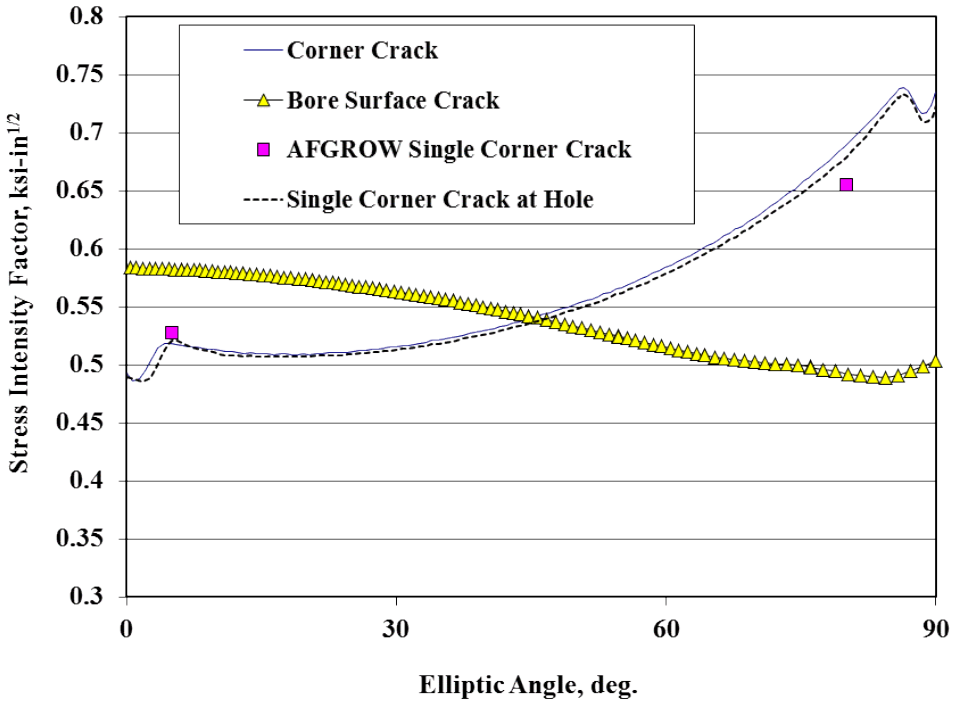
“P-shaped” Crack-Nonsustainable “peak”





Secondary Crack Had Little Influence



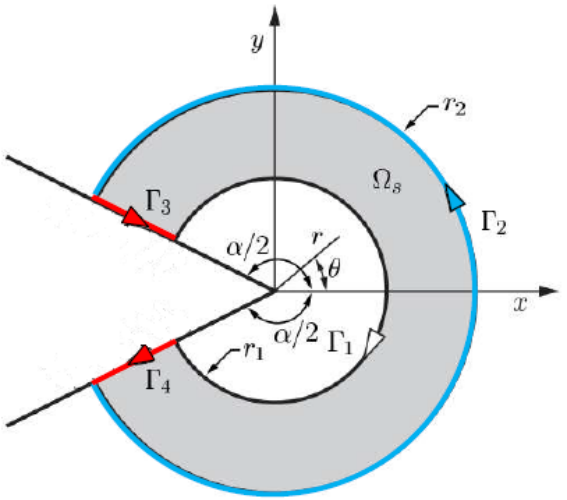


Contour Integral Methods (CIM) prior to 2013

CIM for traction-free cracks(*)

$$K_I = \int_{\Gamma_2} \left(T_x^{(u)} v_x + T_y^{(u)} v_y - T_x^{(v)} u_x - T_y^{(v)} u_y \right) ds$$

(*) Szabó, B. A. and Babuska, I. *Finite Element Analysis*, John Wiley and Sons, Inc. New York, 1991.



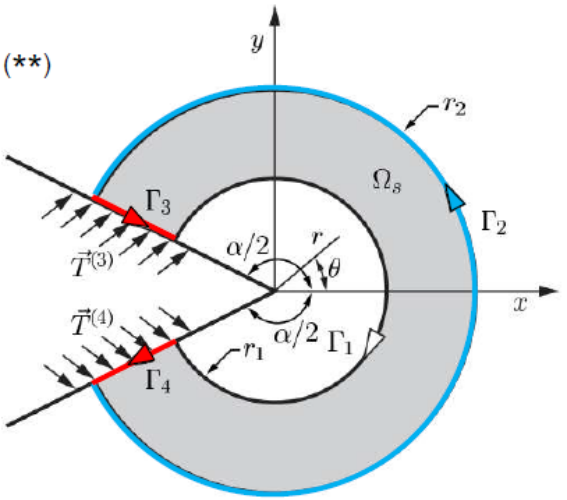
Contour Integral Methods (CIM) after 2013

CIM for traction-free cracks(*)

$$K_I = \int_{\Gamma_2} \left(T_x^{(u)} v_x + T_y^{(u)} v_y - T_x^{(v)} u_x - T_y^{(v)} u_y \right) ds$$

$$+ \int_{\Gamma_3} \left(T_x^{(3)} v_x + T_y^{(3)} v_y \right) ds + \int_{\Gamma_4} \left(T_x^{(4)} v_x + T_y^{(4)} v_y \right) ds.$$

Modification for loaded crack faces (**)

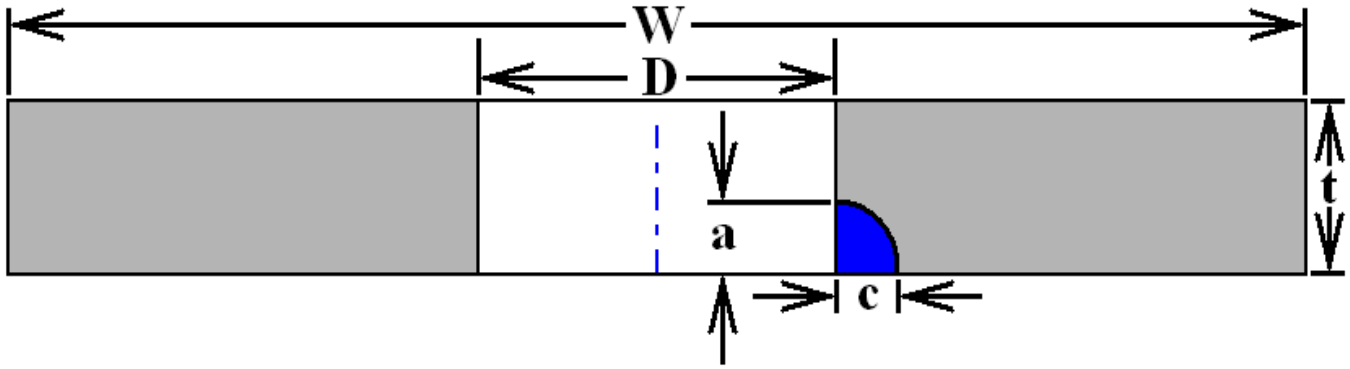


(*) Szabó, B. A. and Babuska, I. *Finite Element Analysis*, John Wiley and Sons, Inc. New York, 1991.

(**) Pereira, J.P. and Duarte, C.A. (2006). *The Contour Integral Method for Loaded Cracks*, Communication in Numerical Methods in Engineering, Volume 22, pp 421-432. DOI: 10.1002/cnm.824

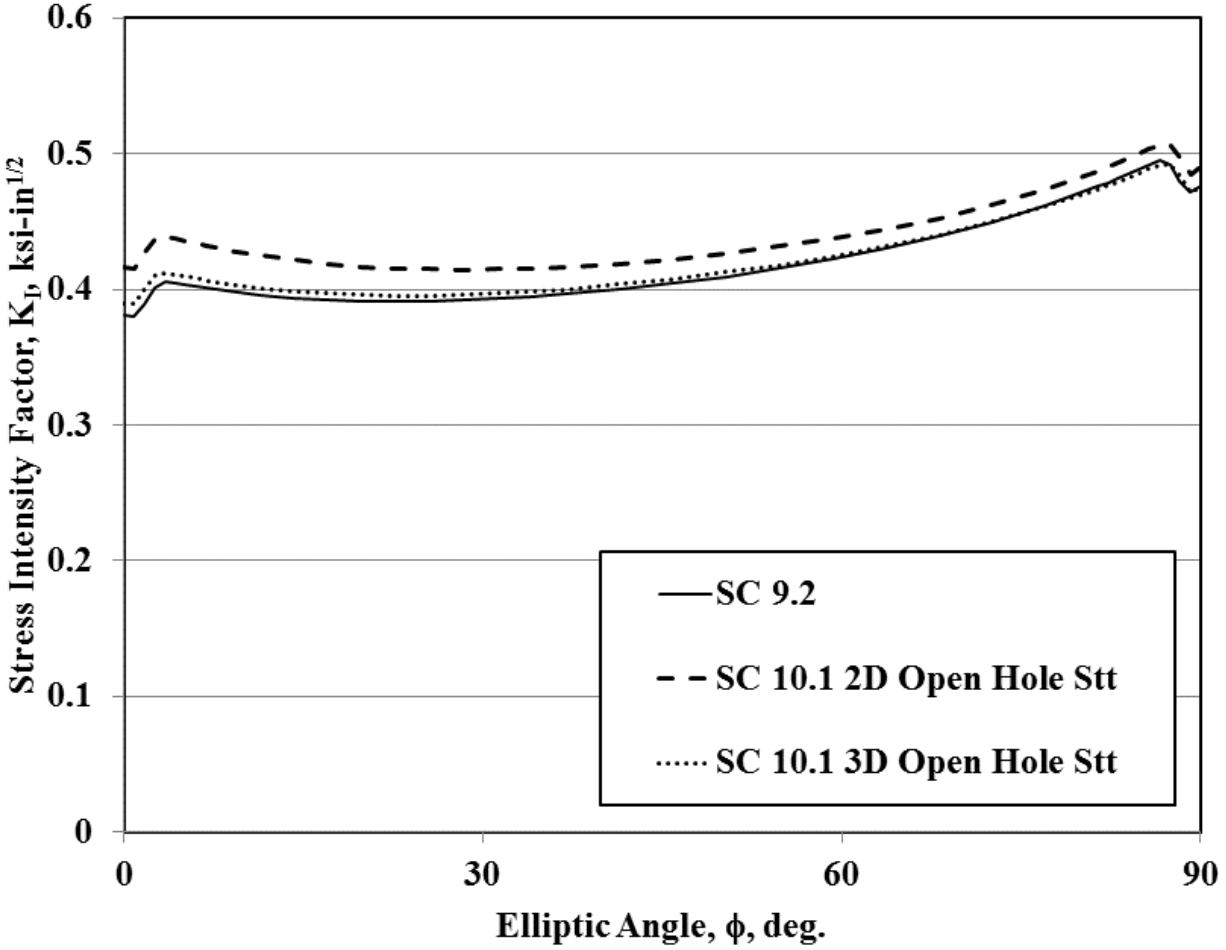
Verification

- Single Corner Crack at Hole
- Highly accurate uncracked stress state computed with StressCheck
- Surface curve fit residual stress—normal traction only on crack face

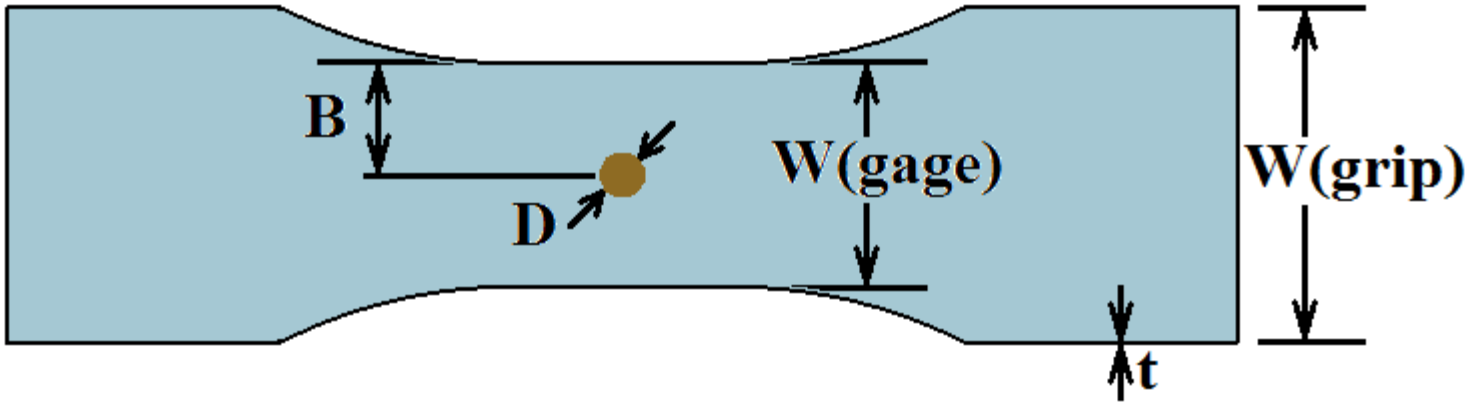


W=2.0 in., B=1.0 in., t=0.25 in., D=0.25 in., a=c=0.05 in.

Using the Right Stress Improves the Verification



Validation-Experiment

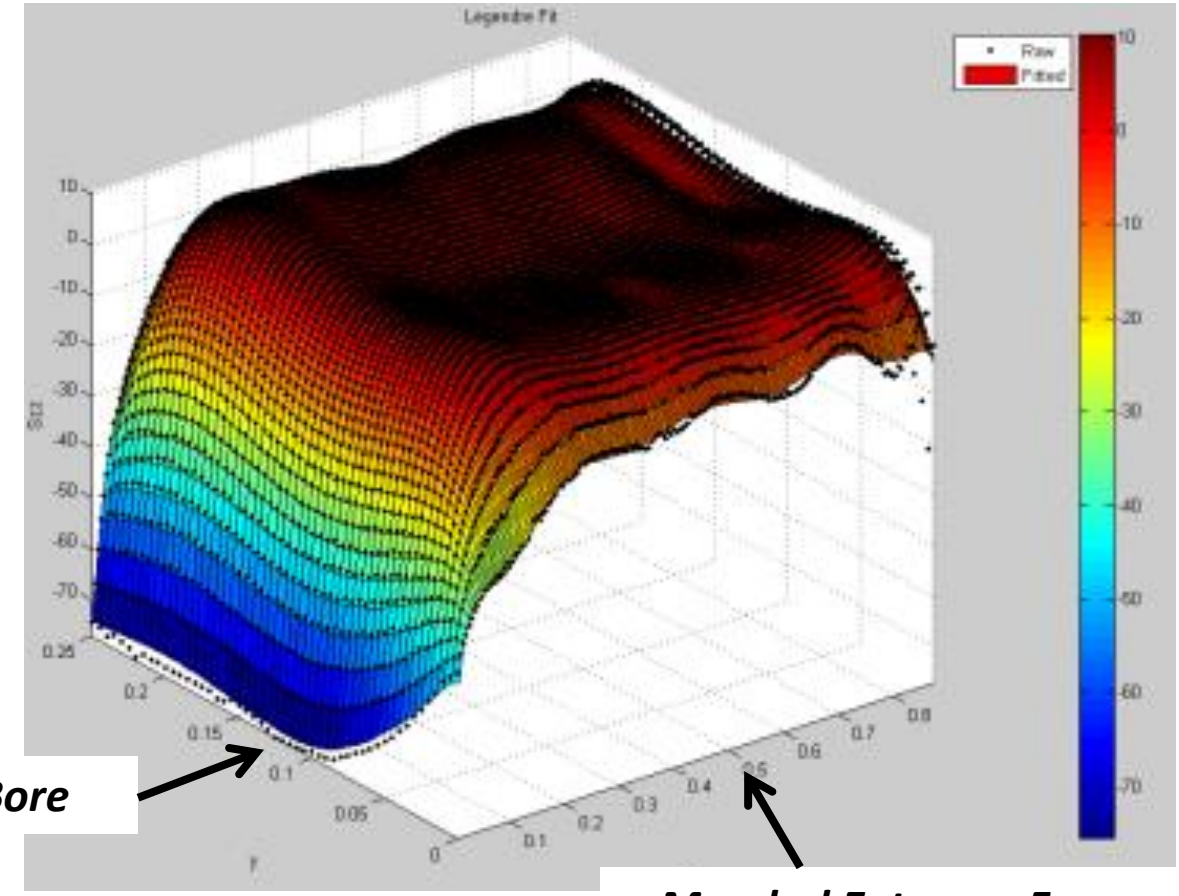


W(grip)=3.0 in., W(gage)=2.0 in., B=1.0 in., t=0.25 in., D=0.25 in.

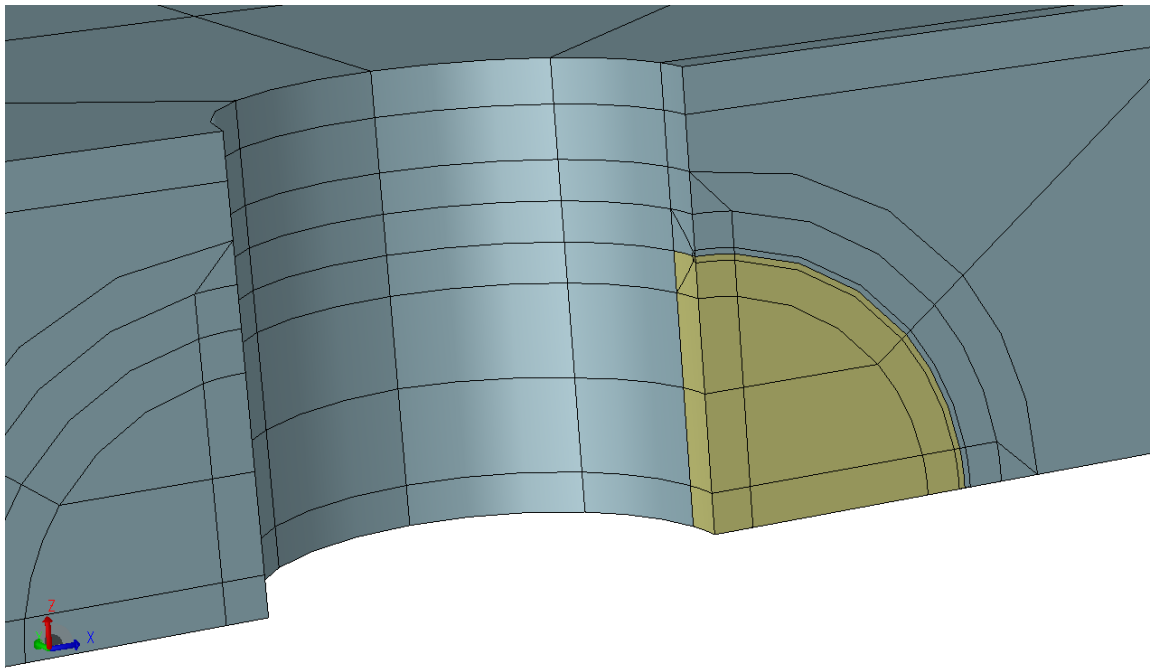
- Max (gage) stress=25 ksi, R=0.0 (CA)
- Initial crack lengths: c_i=0.0281 in., a_i=0.0349 in.

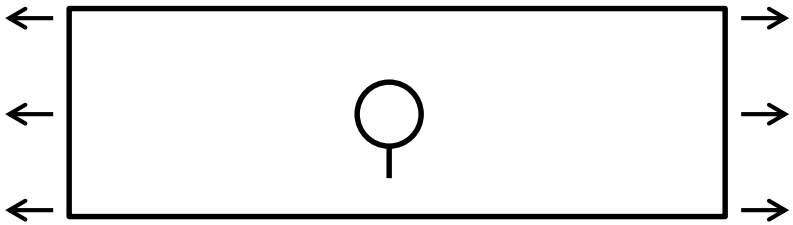
Validation-Residual Stress

W(grip)=3.0 in., W(gage)=2.0 in., B=1.0 in., t=0.25 in., D=0.25 in.



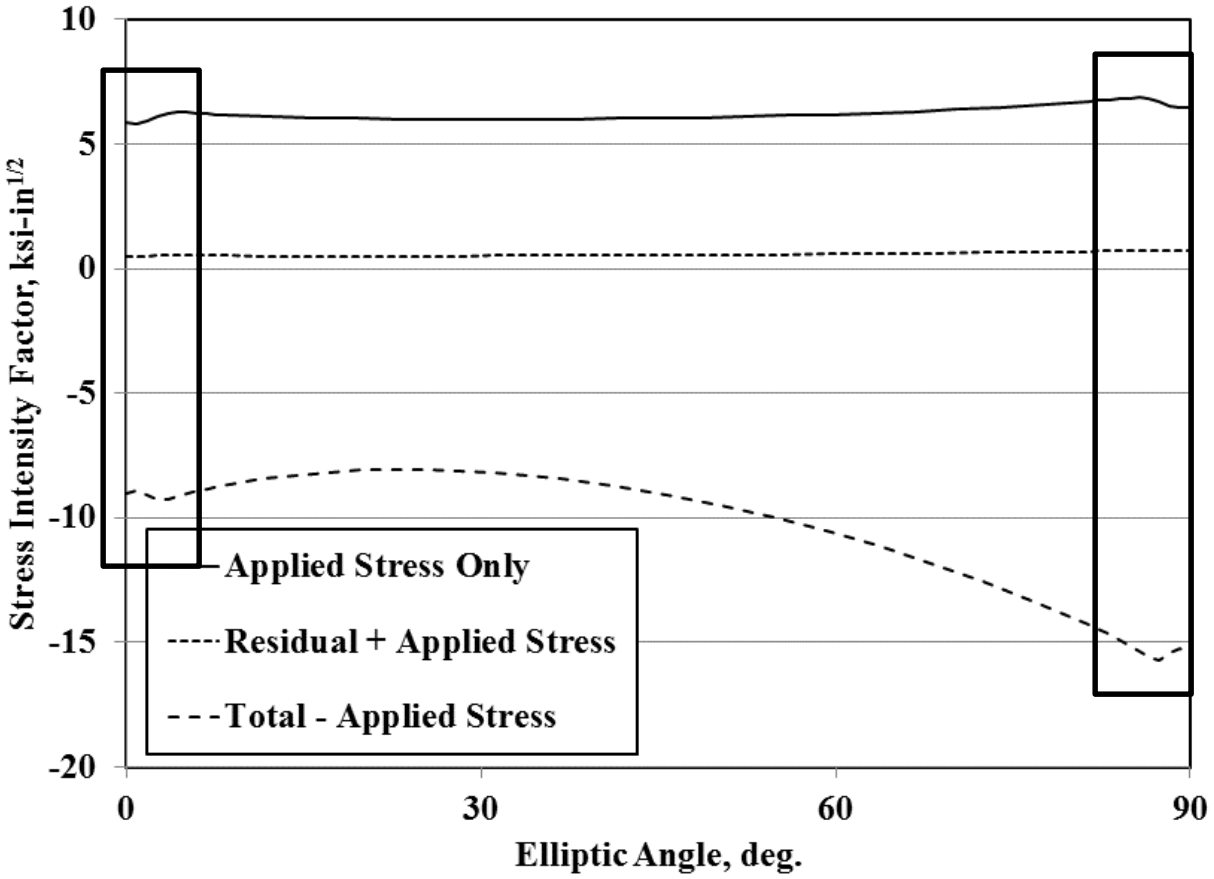
Validation-SC Computed Kres





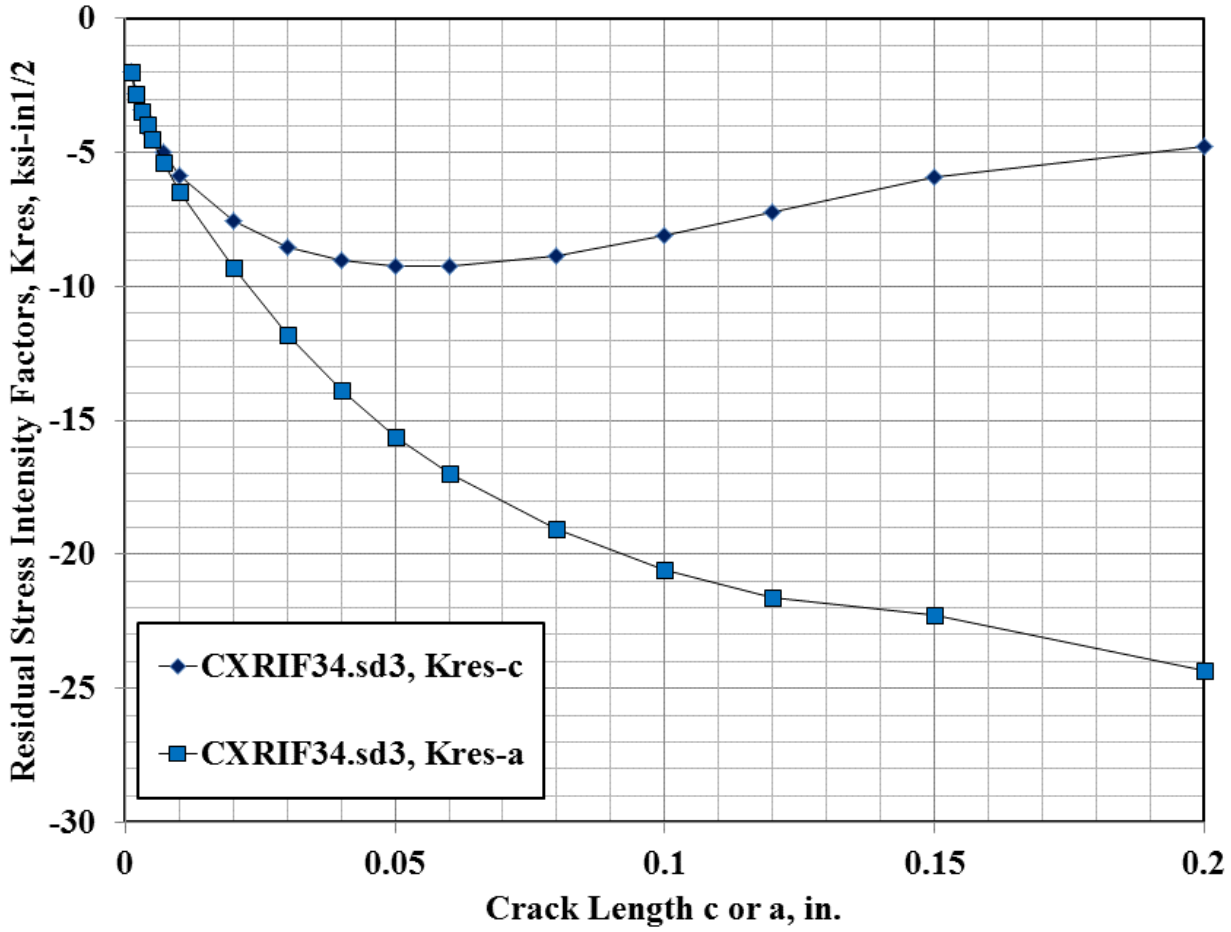
- **Fix a/c=1**
- **Compute SIFs with and w/o Residual Stress on same mesh**

Validation-SC Computed Kres



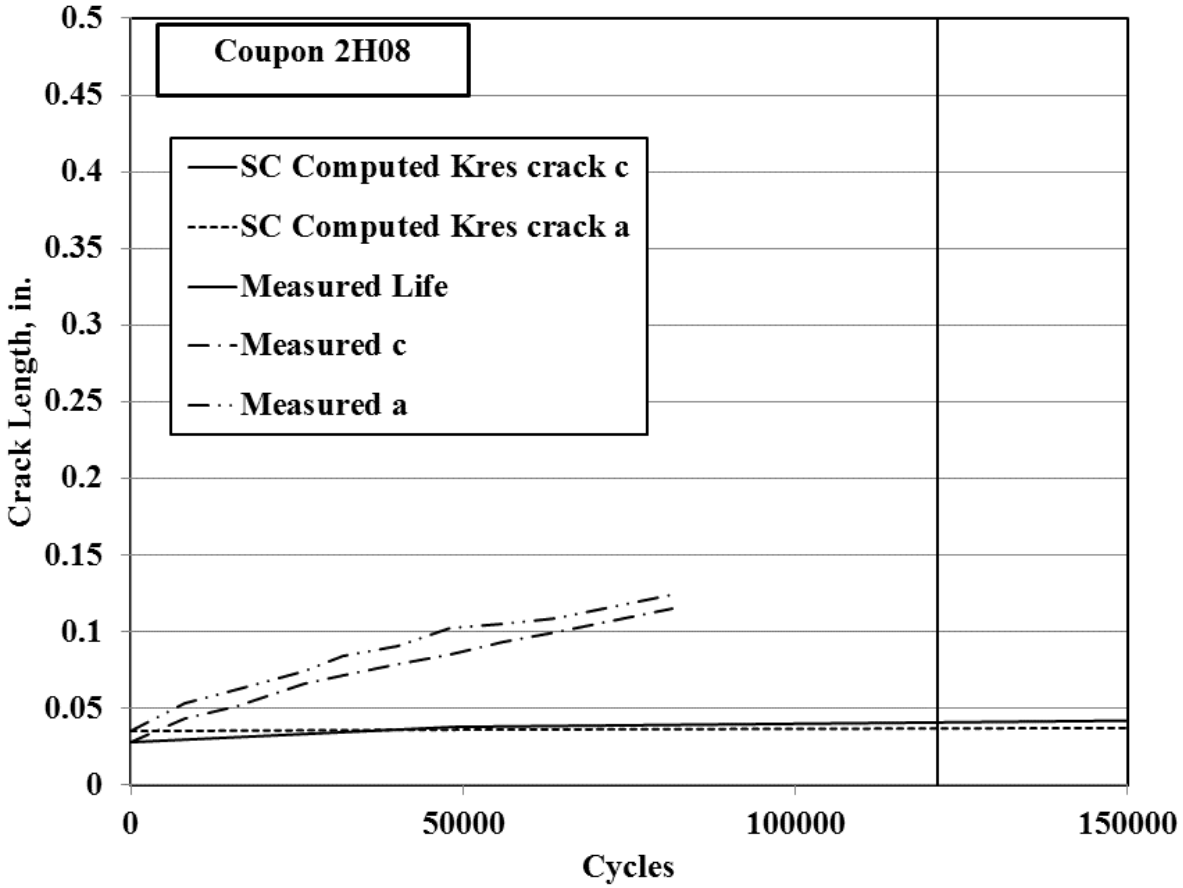
- **Fix a/c=1**
- **Compute SIFs with and w/o Residual Stress**
- **Extract "local" maxima near two free surfaces**

Validation-SC Computed Kres



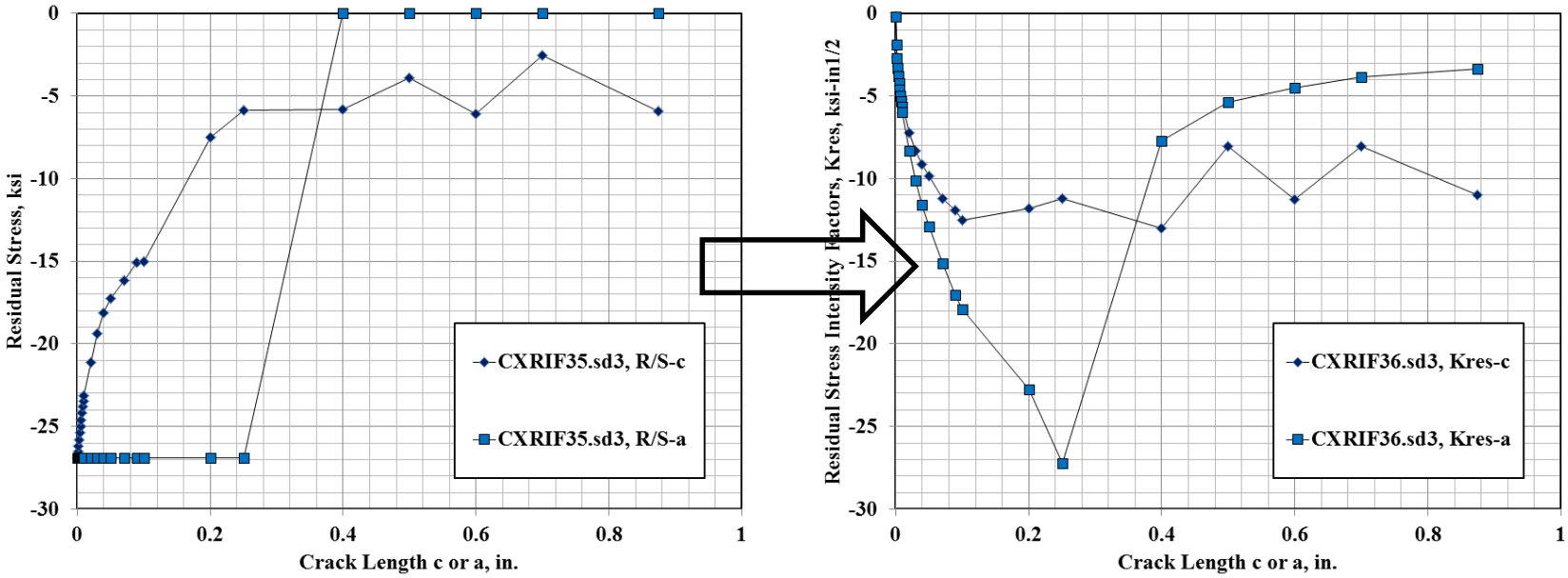
- **Fix a/c=1**
- **Compute SIFs with and w/o Residual Stress**

Validation-SC Computed Kres



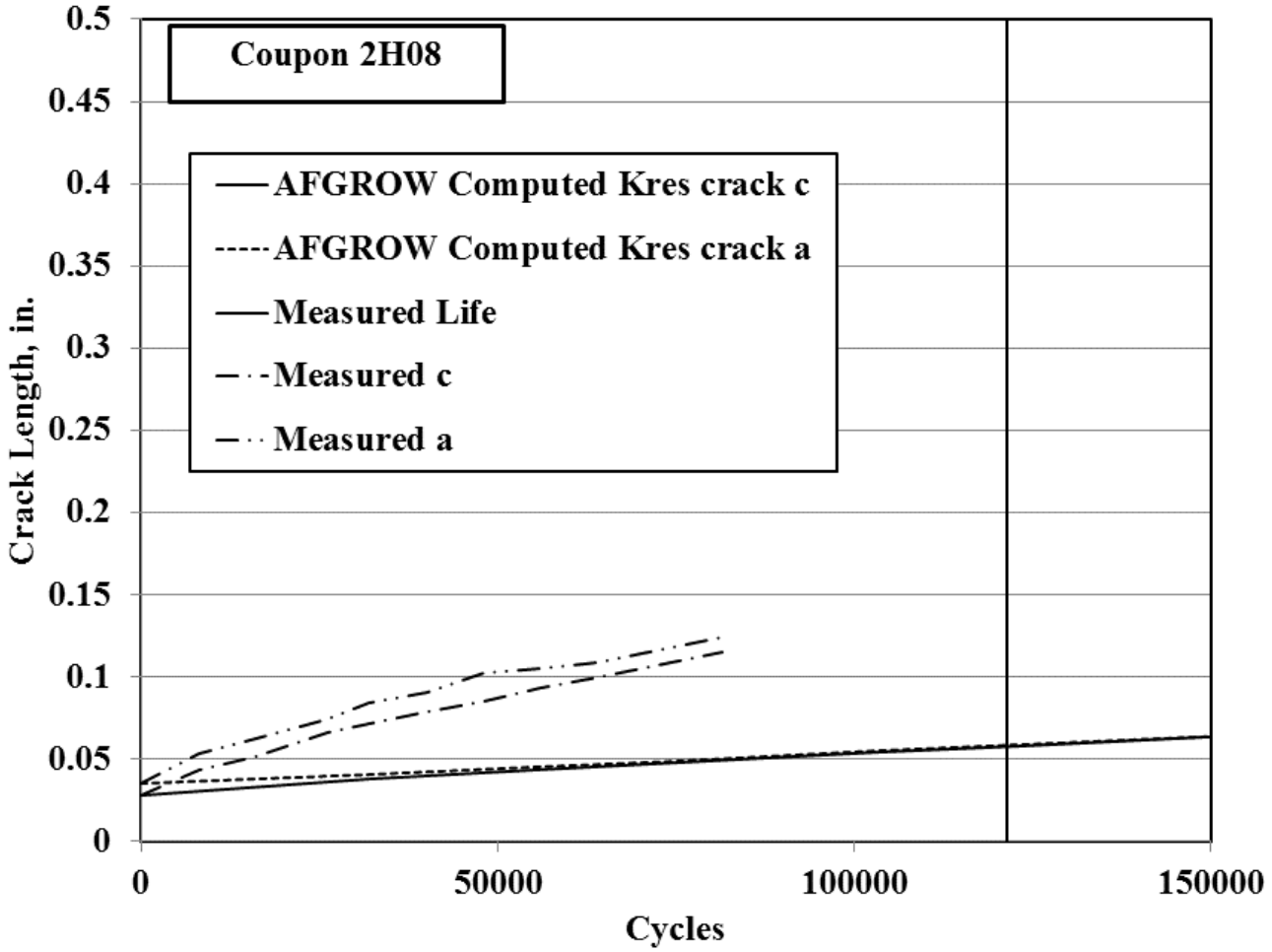
$$K_{max}^{tot} = K_{max}^{applied} + K_{res}$$

Validation-AFGROW Kres



- **Read in Residual Stress in AFGROW's Residual Stress menu**
- **AFGROW computed Residual SIFs**

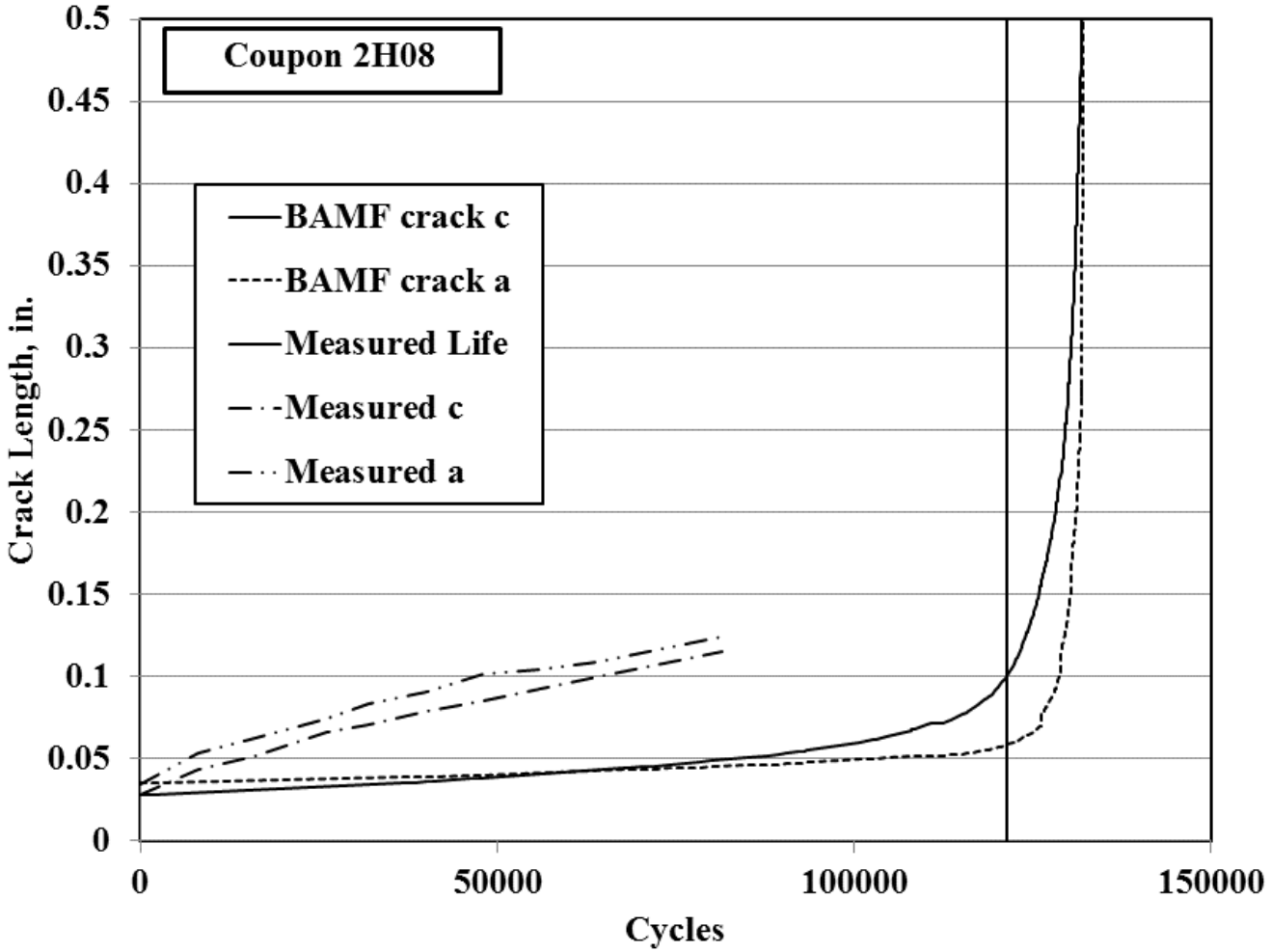
Validation-AFGROW Computed Kres



$$K_{max}^{tot} = K_{max}^{applied} + K_{res}$$

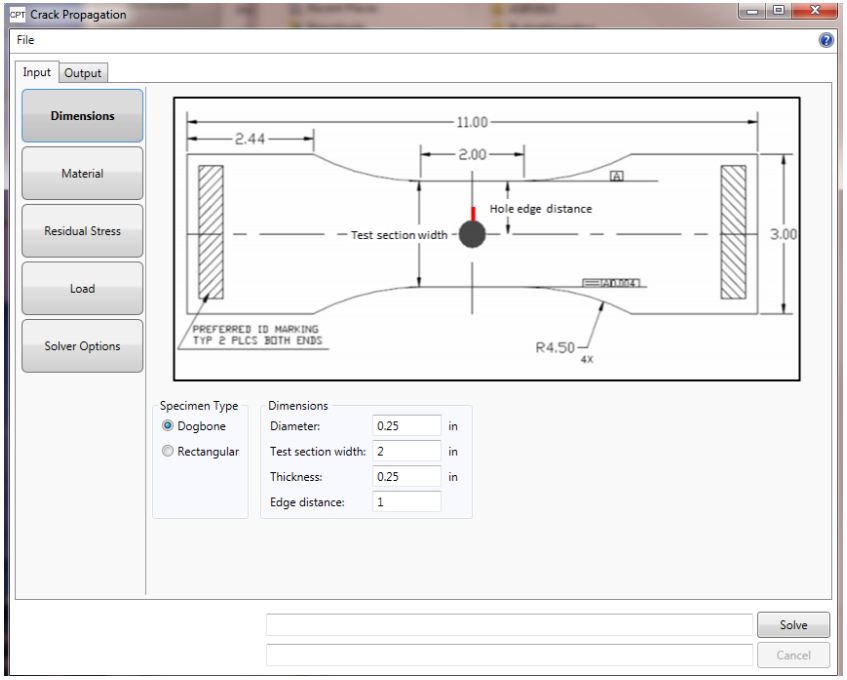
Validation-BAMF

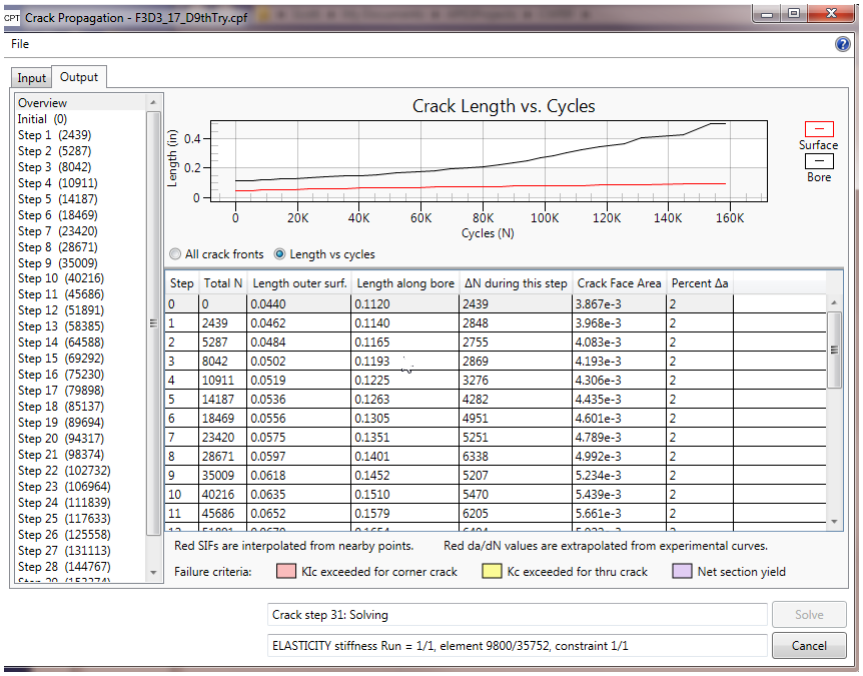
MOVIE



$$K_{max}^{tot} = K_{max}^{applied} + K_{res}$$

Crack Propagation Analysis Tool (CPAT)

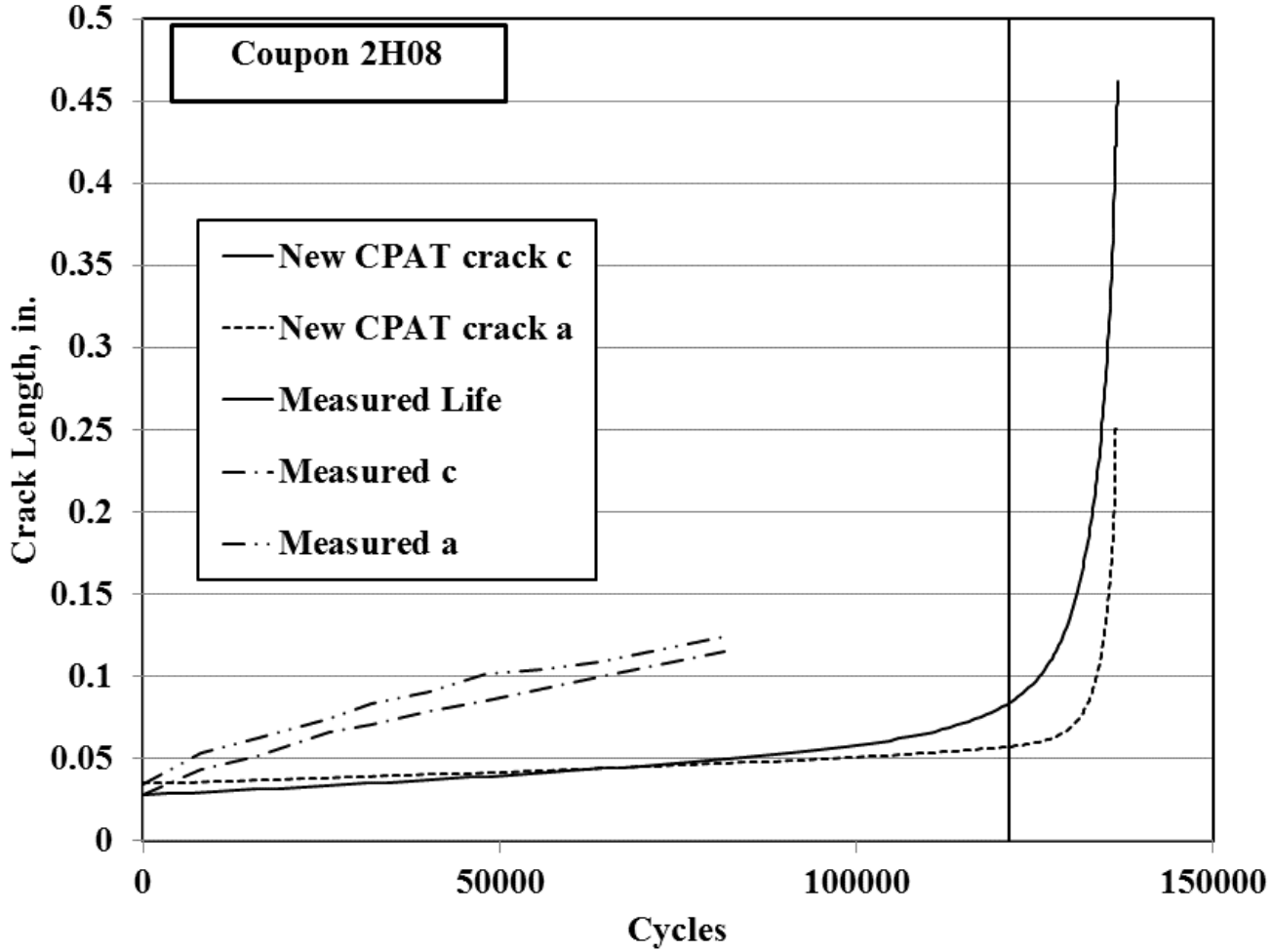




- **Inputs: Geometry (2 types), material, Residual Stress, Load (CA/VA) and initial crack dimensions**

- **Outputs: Evolving crack shapes, (a,c) vs. N.**
- **Individual crack fronts with all computed info**

Validation-CPAT



$$K_{max}^{tot} = K_{max}^{applied} + K_{res}$$

Conclusions

- Allowing crack to evolve to natural shape improved predictions substantially
- New failure criteria needed? For instance, failure occurs when X% of SIFs > Toughness

Acknowledgements

- This work funded by U.S. Air Force contract FA9453-12-C-0218, Rapid Innovation Fund Program, “Integrating Residual Stress Analysis of Critical Fastener Holes into USAF Depot Maintenance”
- ESRD, Inc.—CPAT
- A-10 and Josh Hodges—BAMF