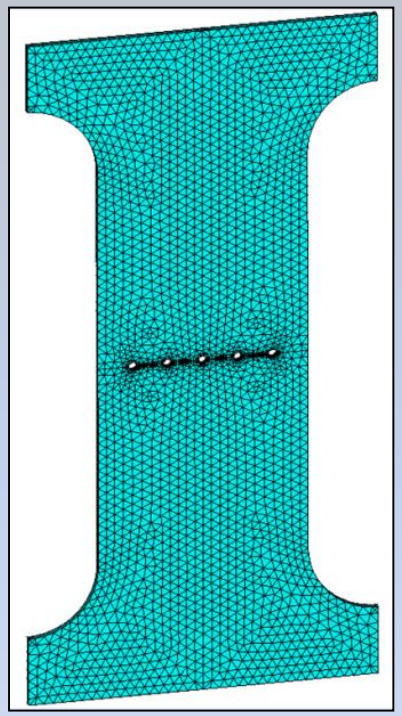
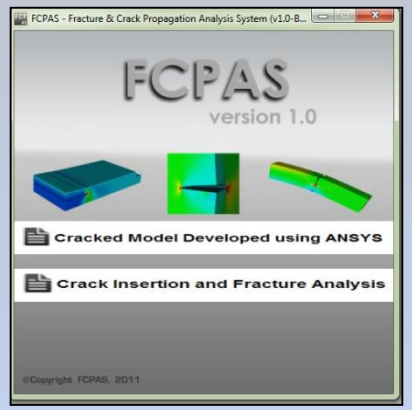
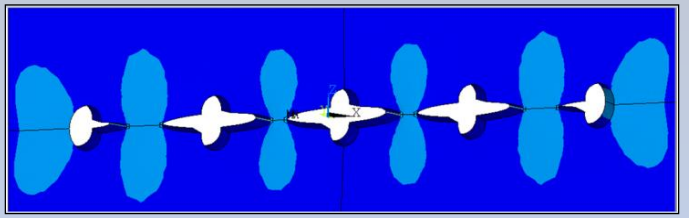
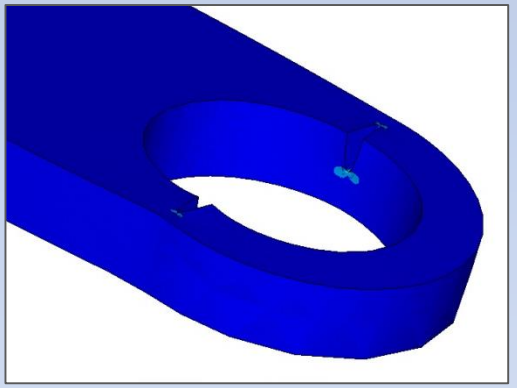
FINITE ELEMENT MODELING OF GROWING MULTIPLE THREE-DIMENSIONAL CRACKS UNDER CYCLIC LOADS









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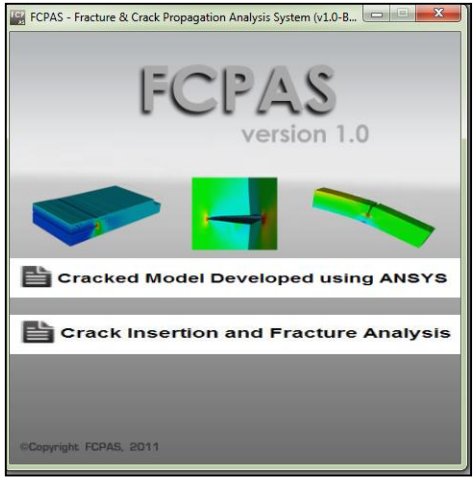
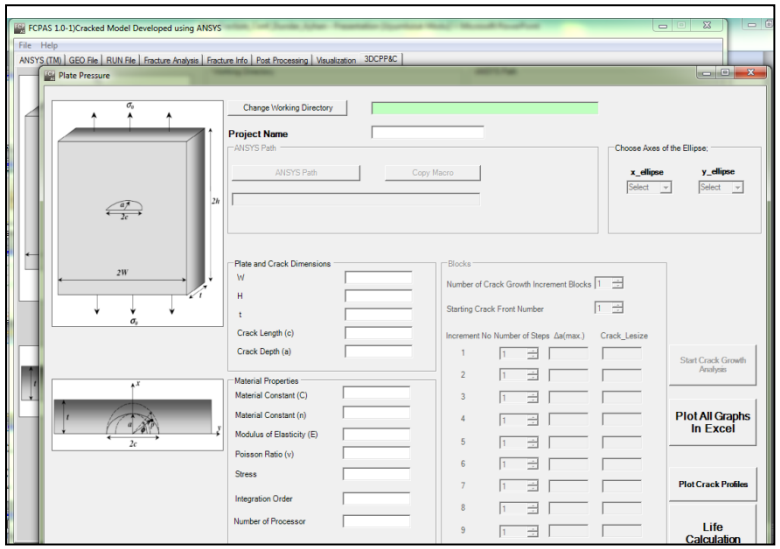
Outline

- FCPAS Standard and Additional Crack Propagation GUI
- Used Tools and Methods for Ellipse Fitting
- Used Tools and Methods for Plotting Analysis Results
- Fracture Analyses of Attachment Lugs for Single and Two Cracks Cases
- Fracture and Crack Propagation Analyses of 2024 Al Alloy Multiple Crack Specimen and 7050 Al Alloy Specimen with Two Surface Crack
  - *Problem Description*
  - *Finite Element Fracture Models*
  - *Stress Intensity Factor Solutions*
  - *Crack Propagation Analyses*
  - *SIF Results*
  - *Comparison with Results in Literature*
  - *Crack Profiles and Stress Contours*
- Summary and Conclusions

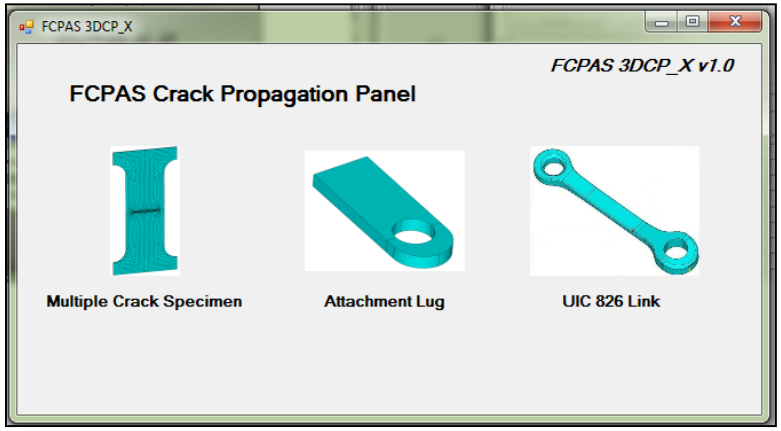
FCPAS GUI

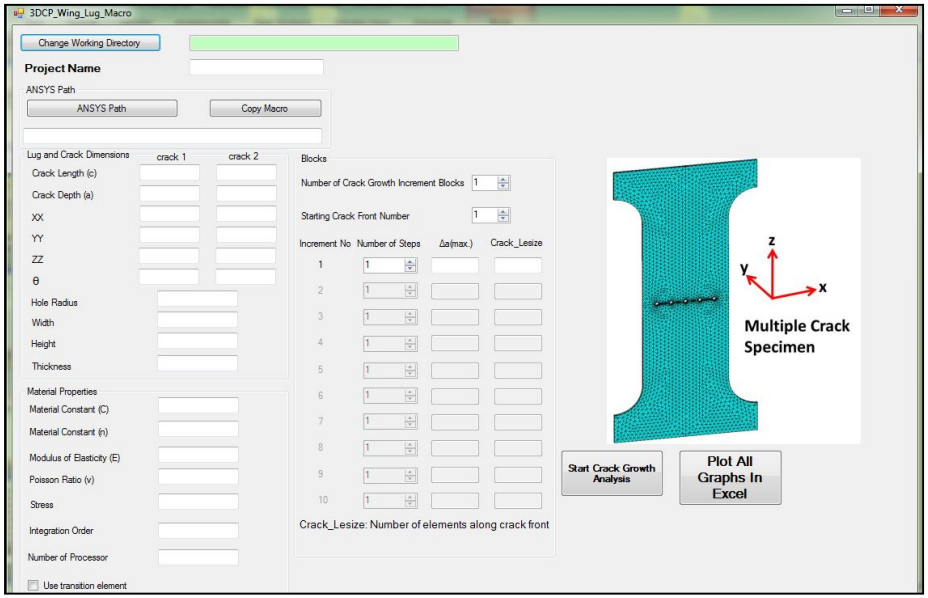
FCPAS Standard GUI



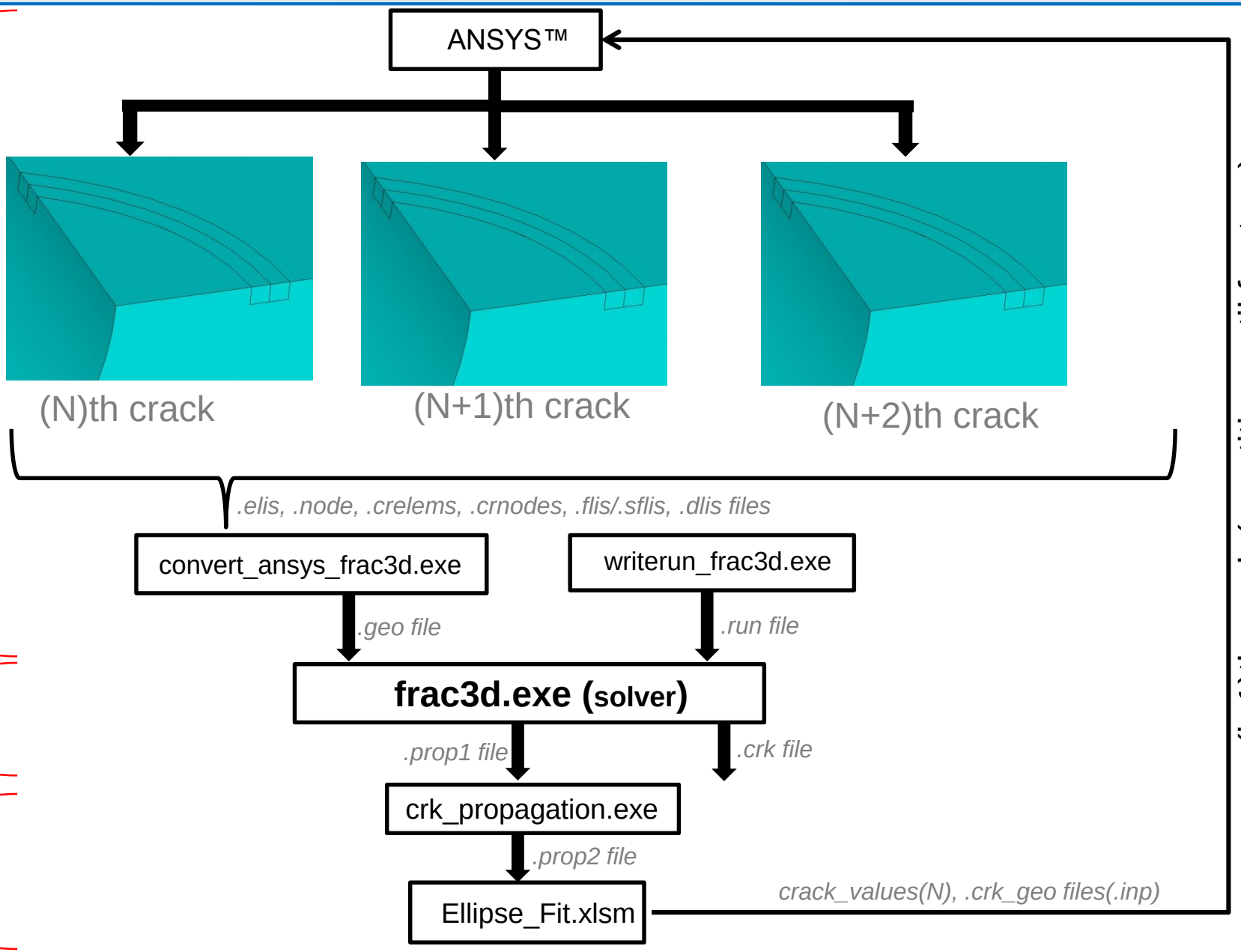


FCPAS Additional Crack Propagation GUI

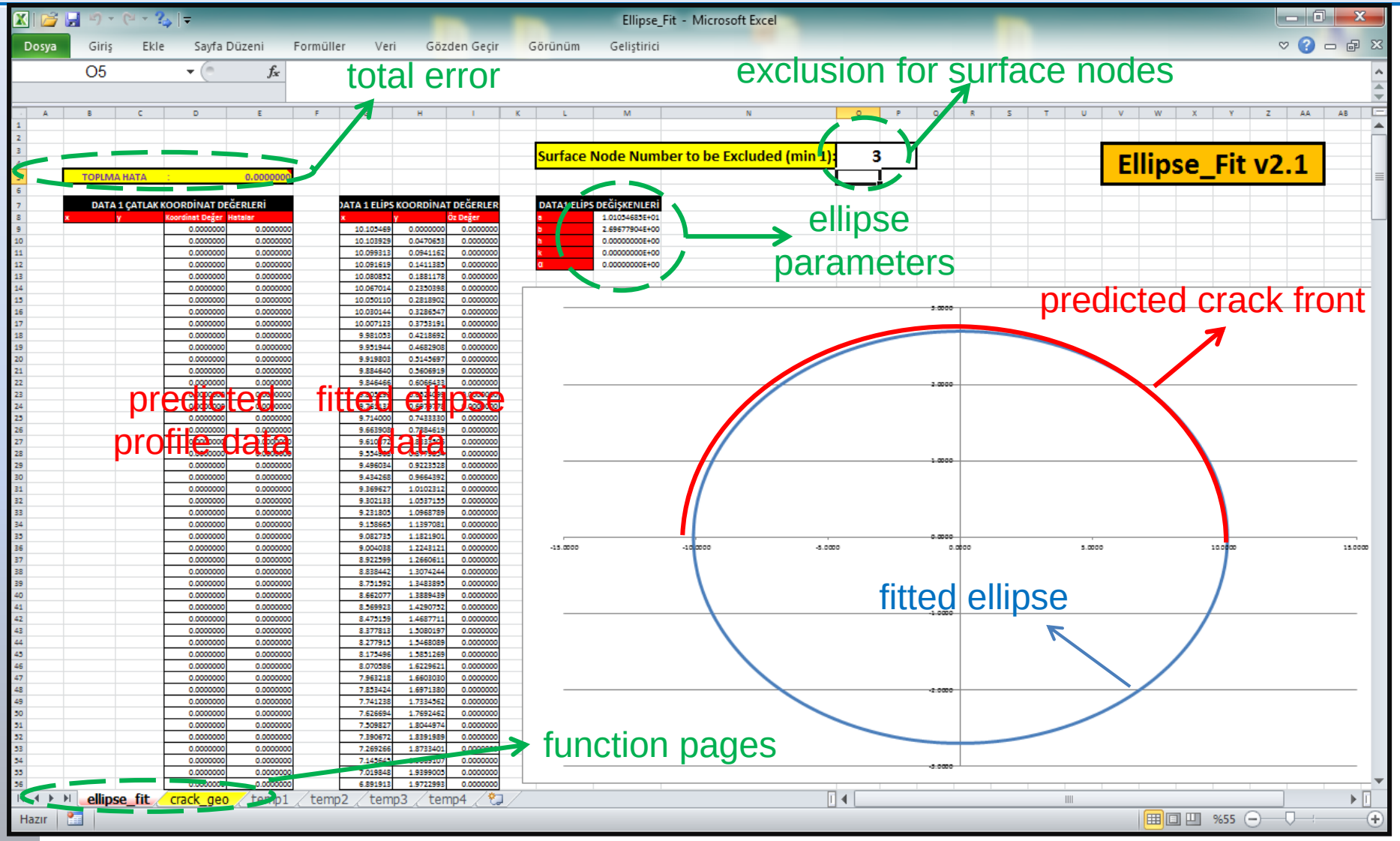




How FCPAS Works For Multiple Cracks?

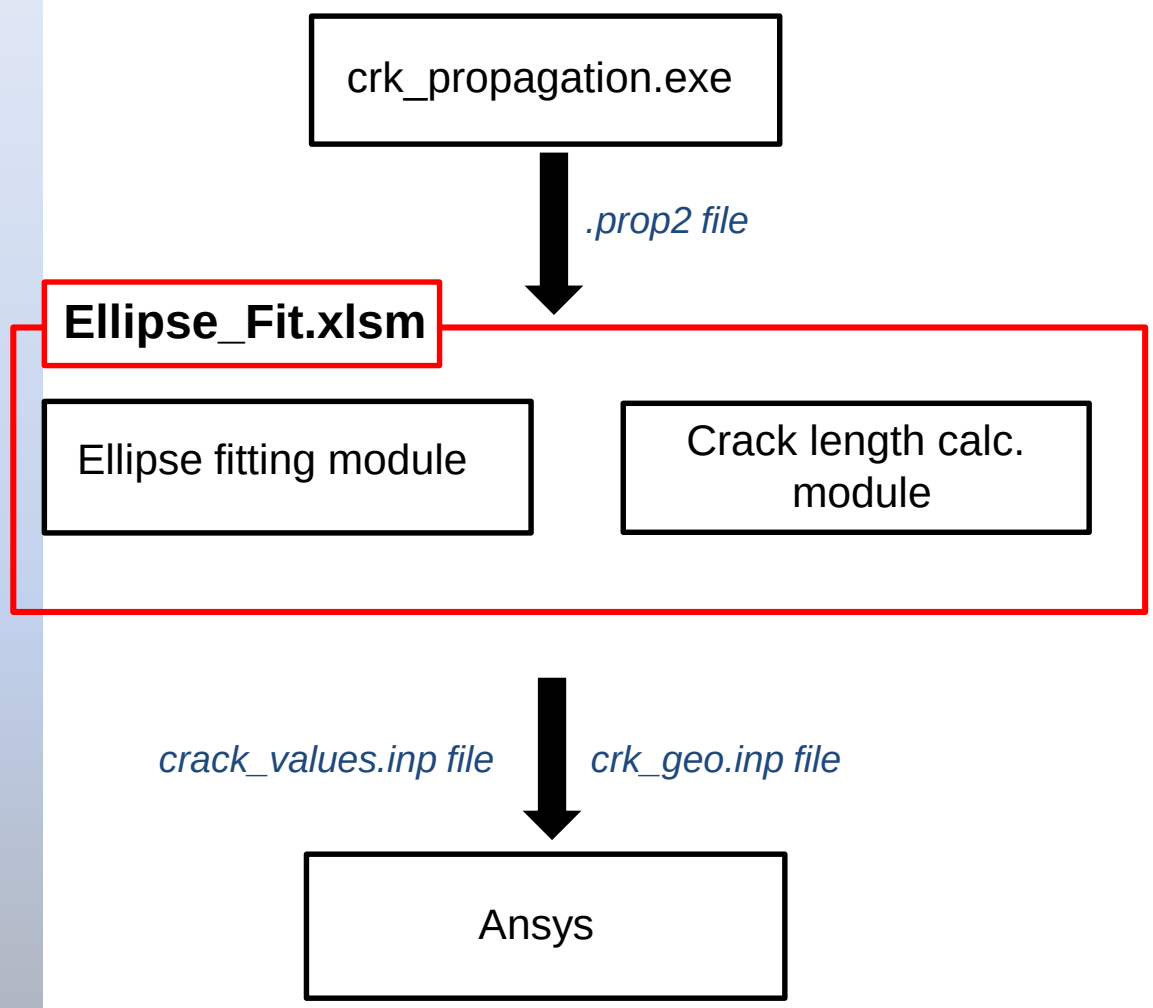


New Ellipse Fitting Method: Automated Excel Solver



Automated Excel File by VBA Macro Code

New Ellipse Fitting Method: Automated Excel Solver



Prediction of next crack profile

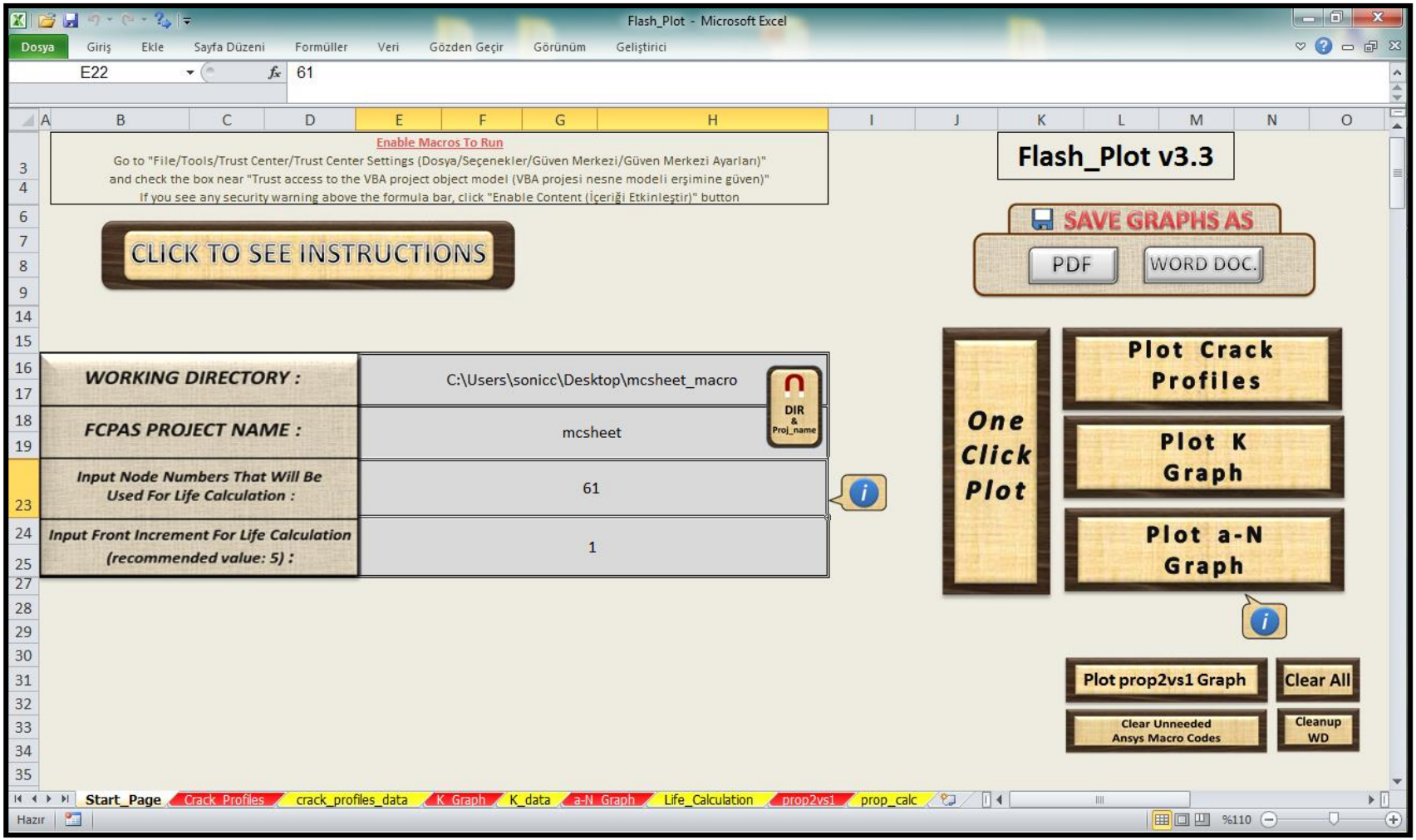
Automatic Ellipse Fitting

(Automatic detection of crack tip mesh number, crack number and crack length)

Modelling of new crack

Ellipse_Fit.xlsm Work Flow Scheme

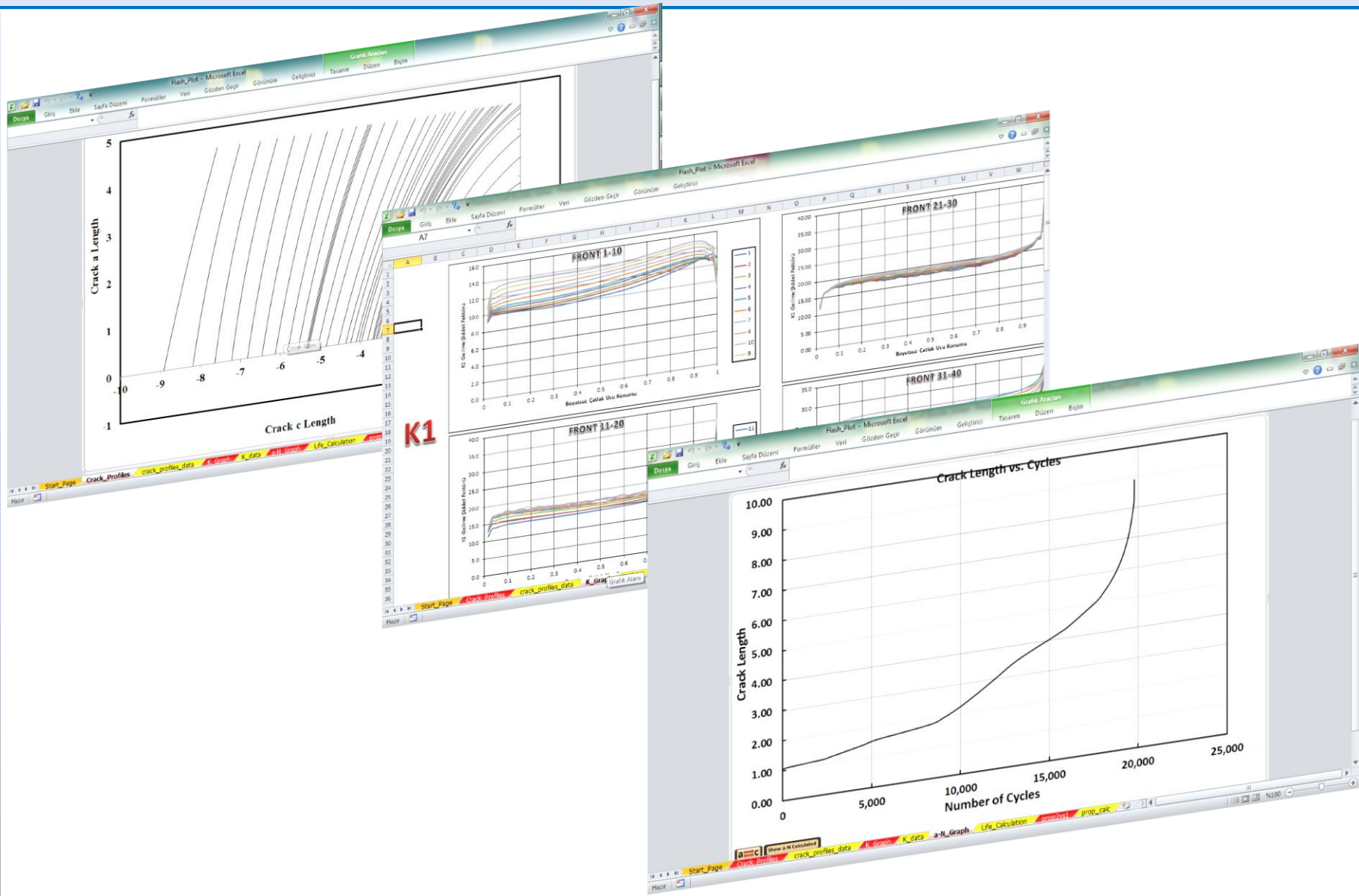
Automated Plotting Tool: Flash_Plot



Flash_Plot.xlsm main page

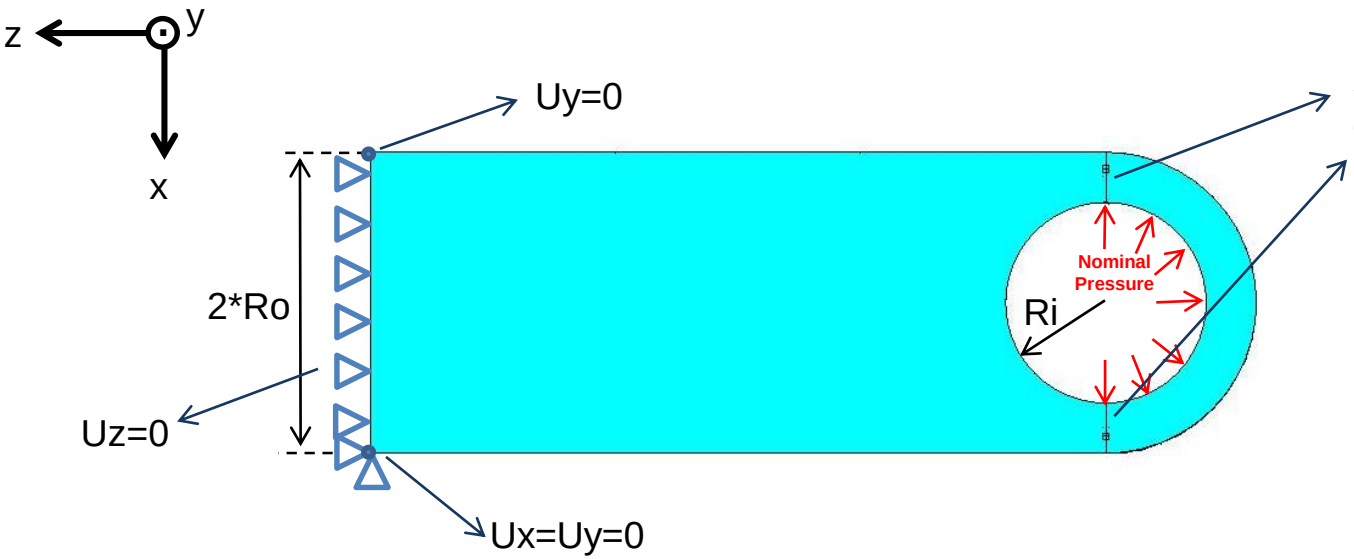
Automated Excel File by VBA Macro Code

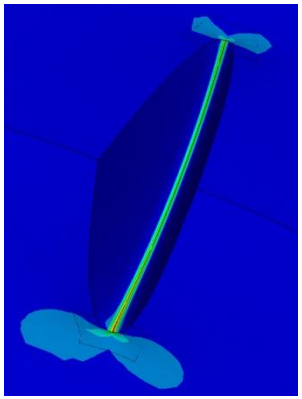
Automated Plotting Tool: Flash_Plot



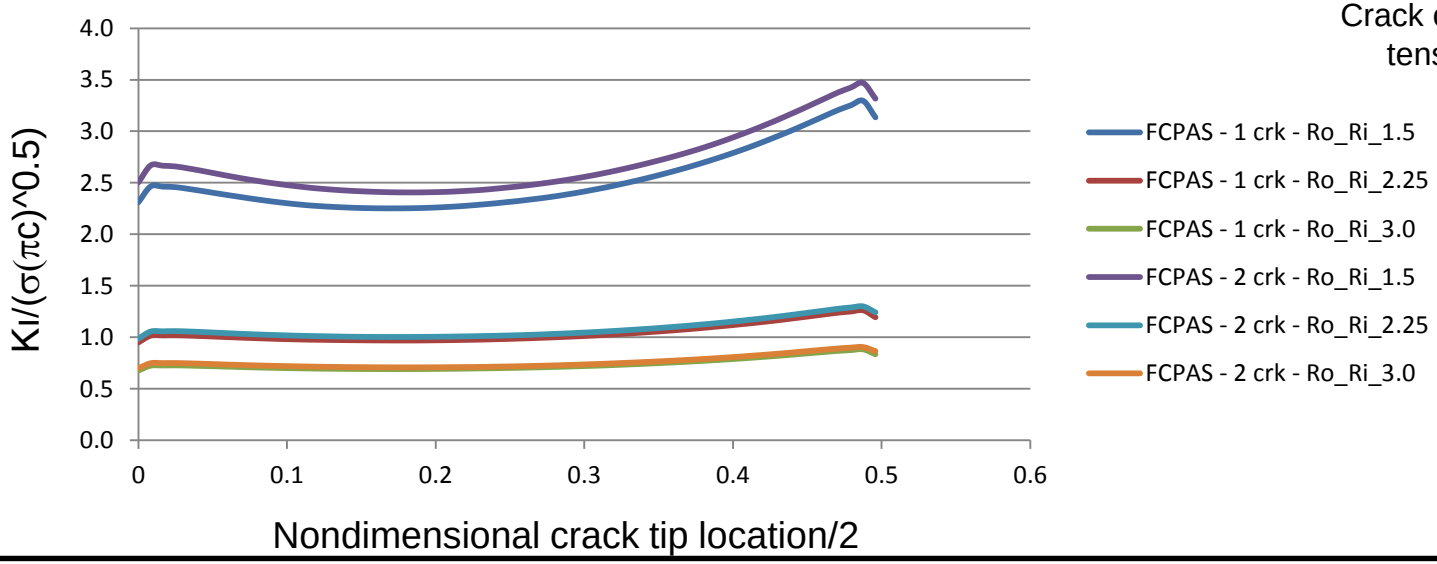
Crack_Profiles, K_Graph and a-N Graph pages of Flash_Plot.xlsm

Multiple Crack Containing Attachment Lug - Problem Description





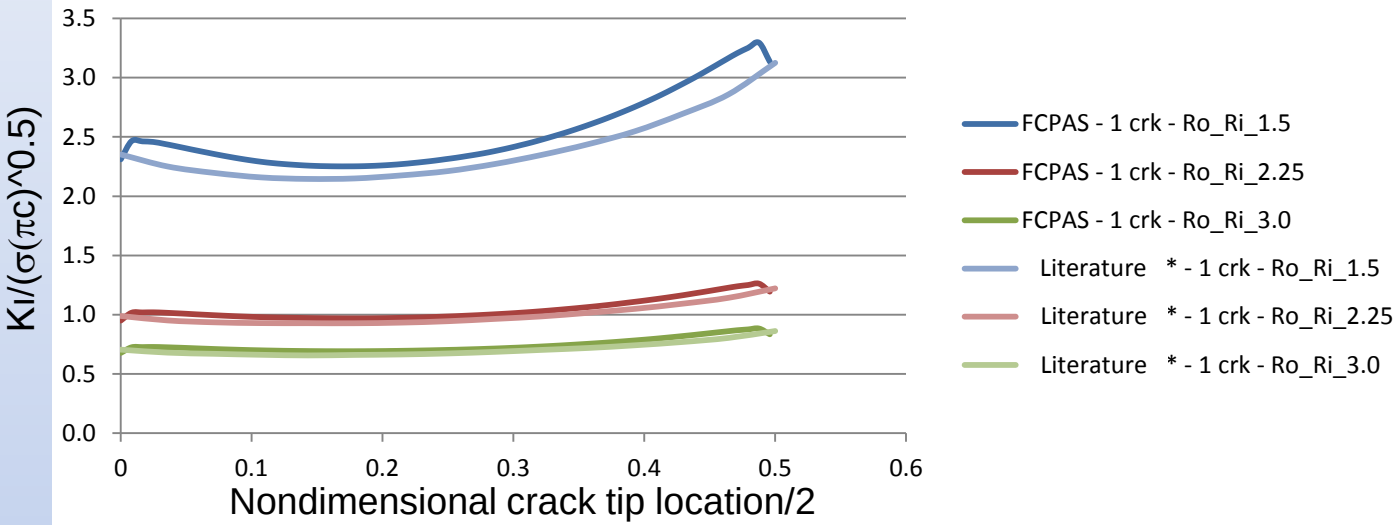
Crack opening under tensile loading



Attachment Lug SIF Comparison For Single and Two Cracks with Different Ro/Ri Ratios

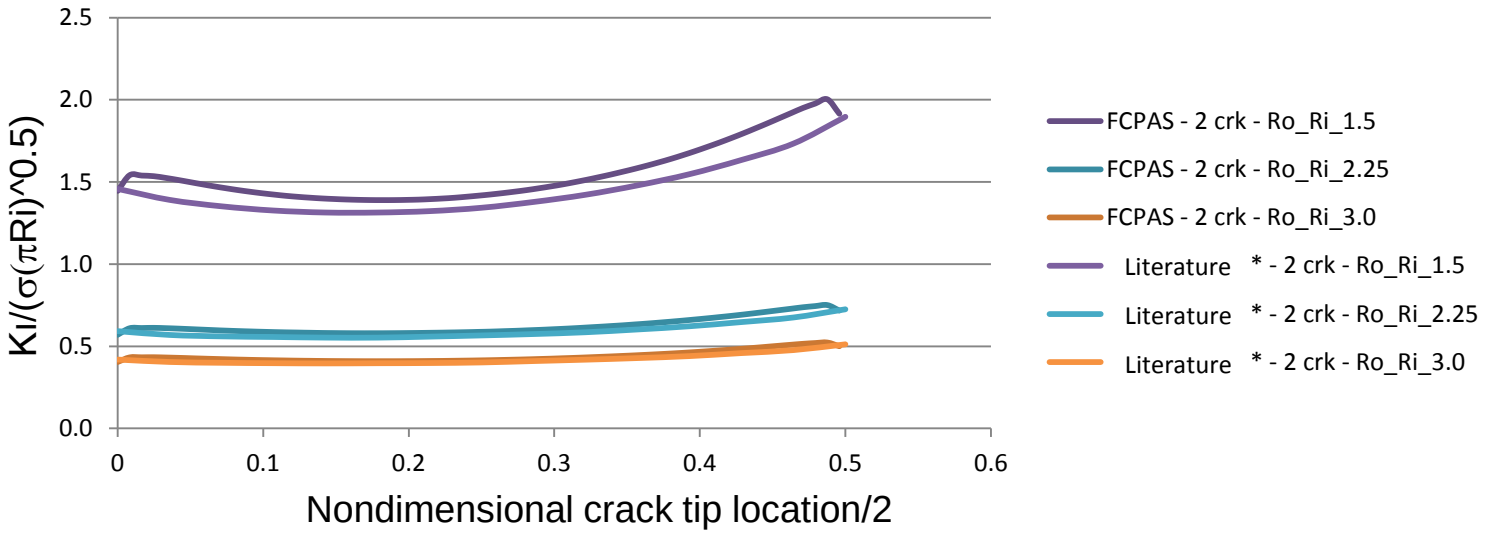
* R. RIGBY and M. H. ALIABADI, Stress intensity factors for cracks at attachment lugs, Engineering Failure Analysis, Vol. 4, No. 2, 1997, pp. 133, 146

Multiple Crack Containing Attachment Lug – Results



Single crack SIF comparison

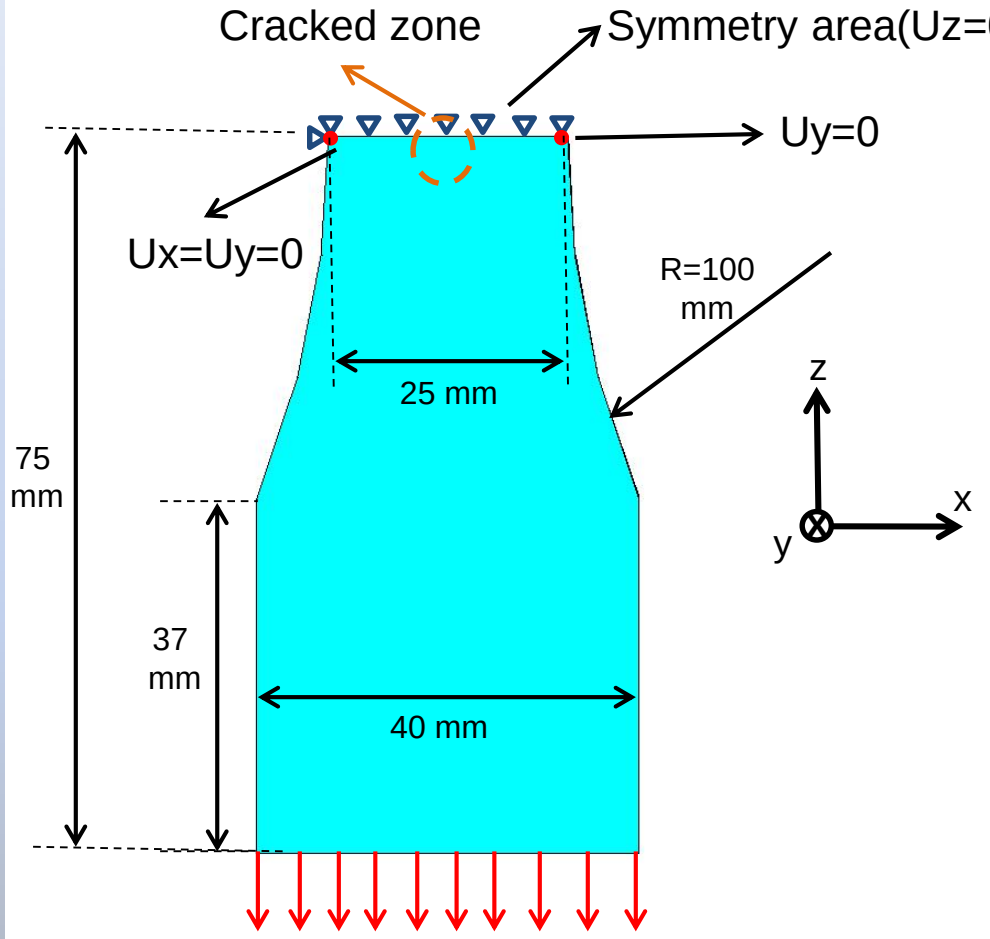
Double crack SIF comparison



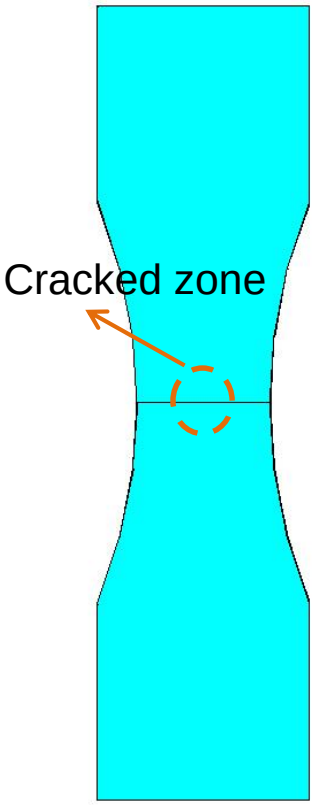
*SIF comparison between FCPAS solutions and experimental data**

* R. RIGBY and M. H. ALIABADI, Stress intensity factors for cracks at attachment lugs, Engineering Failure Analysis, Vol. 4, No. 2, 1997, pp. 133, 146

Specimen with Two Surface Crack - Problem Description



Symmetric Model and Details



Full Model

Crack propagation formulation:

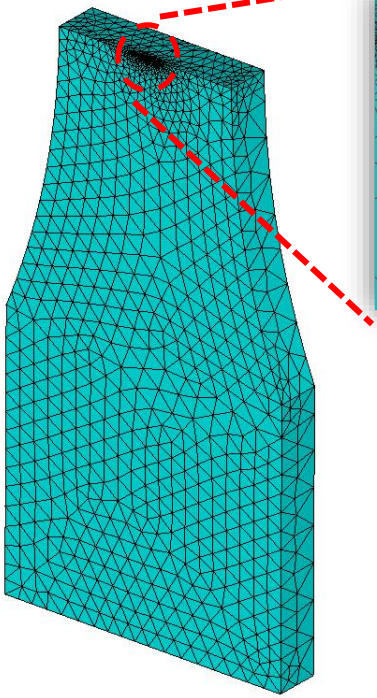
$$da/dN = C\Delta K^{m}$$

C= 6.0E-10, m=2, K_{IC}= 35Mpa*
(7050-T7451 Al Alloy)

Symmetric and Full Model of Multiple Crack Specimen

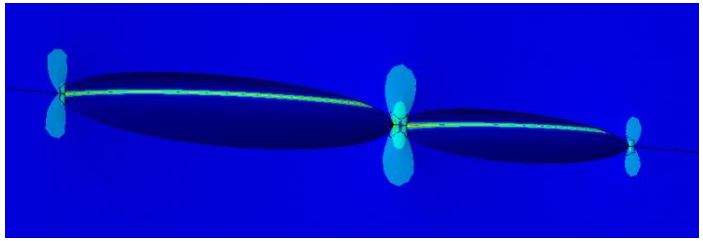
* J.T. Tan and B.K. Chen , A new method for modelling the coalescence and growth of two coplanar short cracks of varying lengths in AA7050-T7451 aluminium alloy, International Journal of Fatigue, Vol. 49, 2012, pp 73–80

Specimen with Two Surface Crack – FE Model

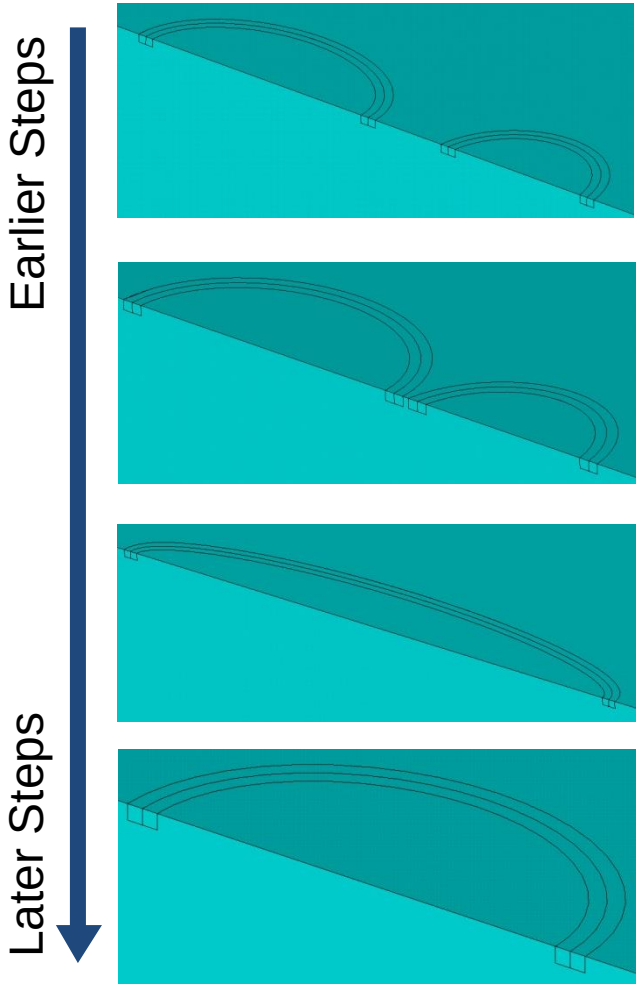


Fe Model of Multiple crack containing specimen

Fe Model of two unsymmetric planar surface cracks

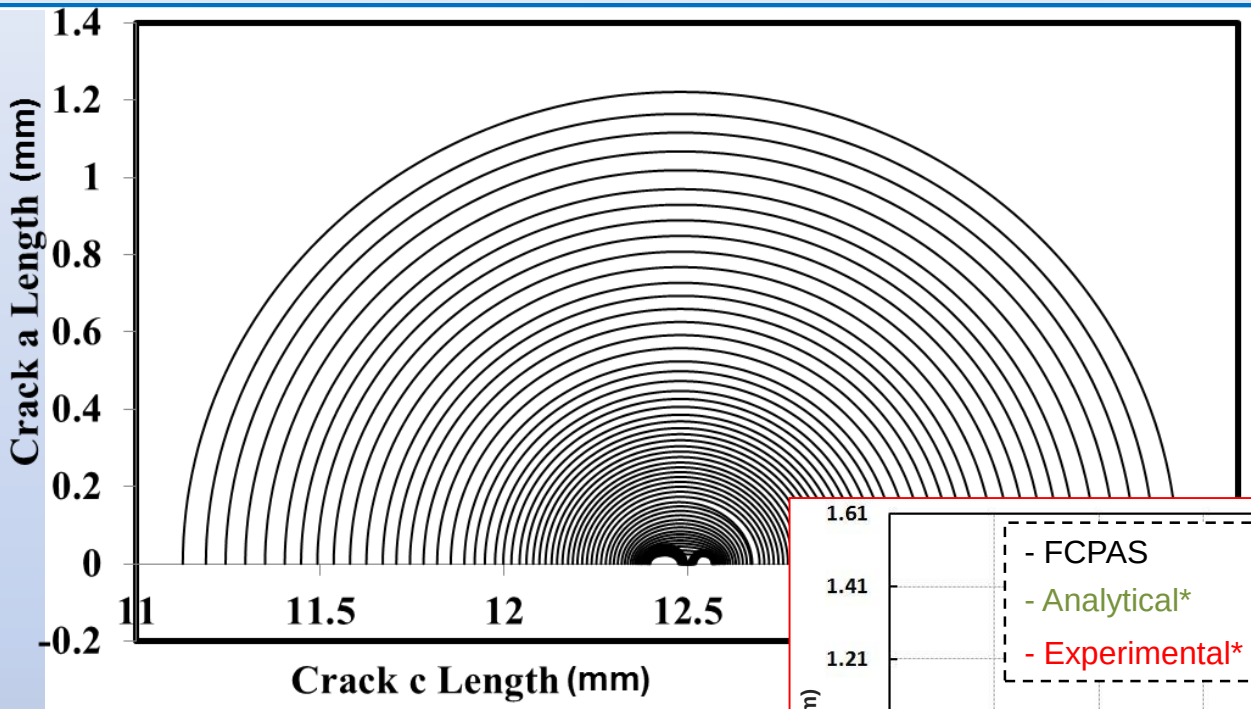


High stresses along crack front and between the close cracks



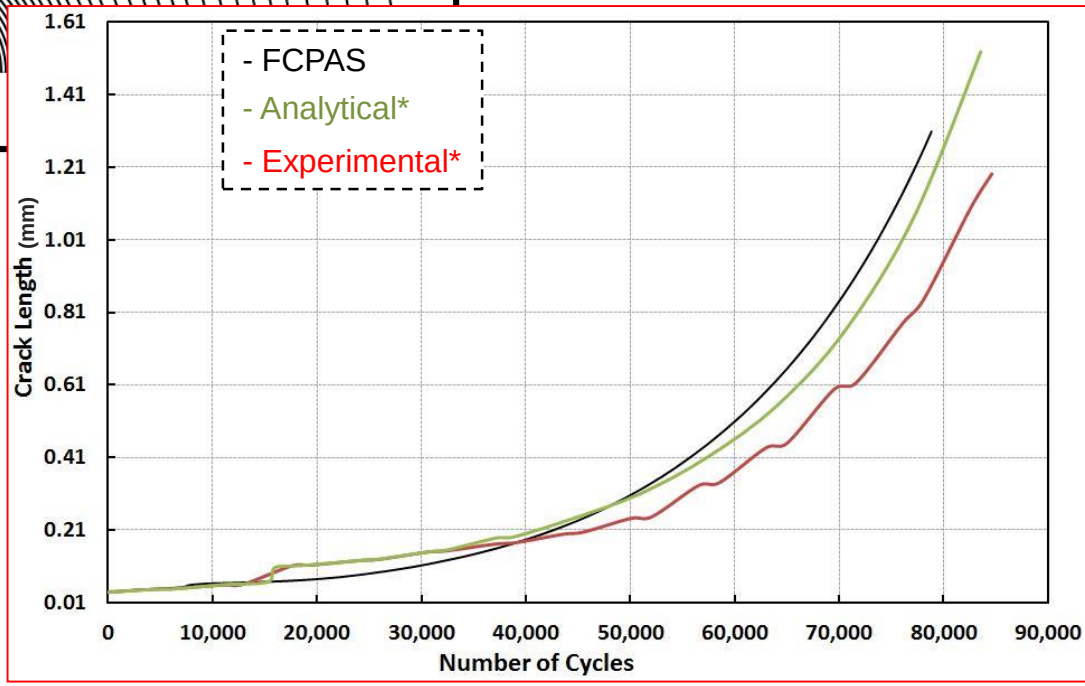
FE Model and Crack Develop Steps

Specimen with Two Surface Crack - Results



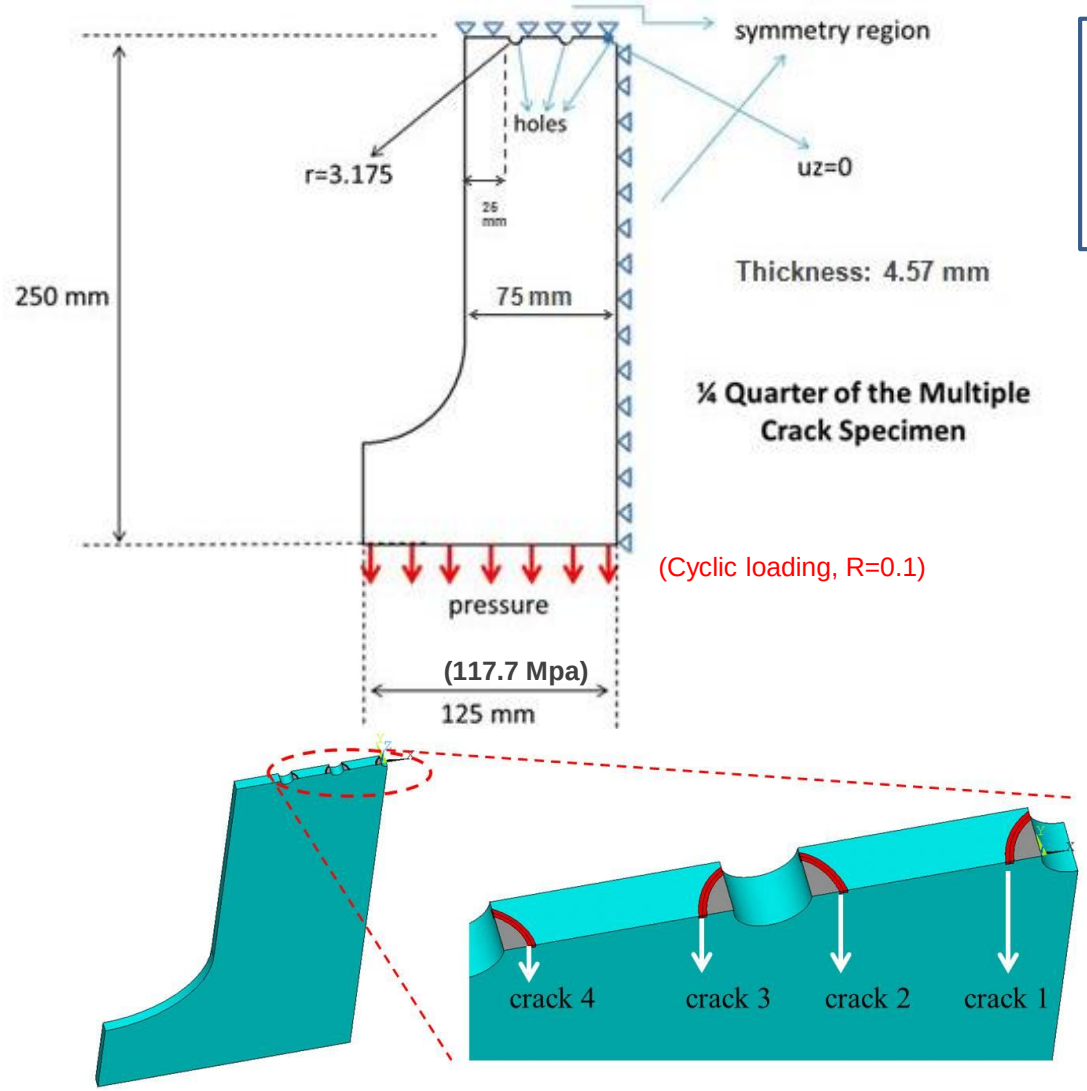
Crack Profiles (FCPAS)

Life Comparison



* J.T. Tan and B.K. Chen , A new method for modelling the coalescence and growth of two coplanar short cracks of varying lengths in AA7050-T7451 aluminium alloy, International Journal of Fatigue, Vol. 49, 2012, pp 73–80

Multiple Crack Specimen - Problem Description



Crack propagation formulation:

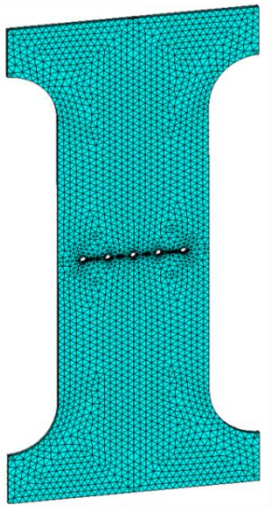
$$da/dN = C\Delta K^{m}$$

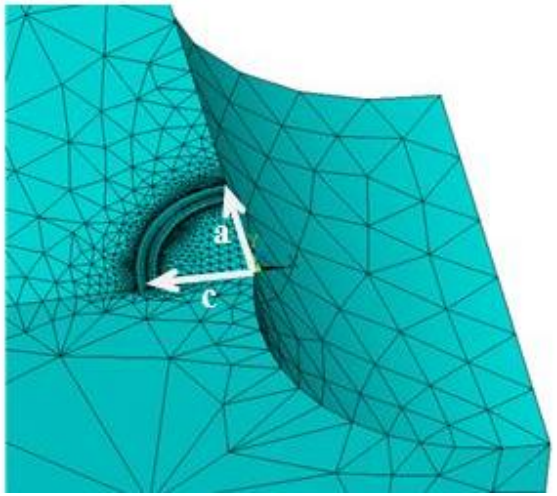
C= 3.95E-11, m=3.5, K_{ic}= 37Mpa* (2024-T3 Al Alloy)

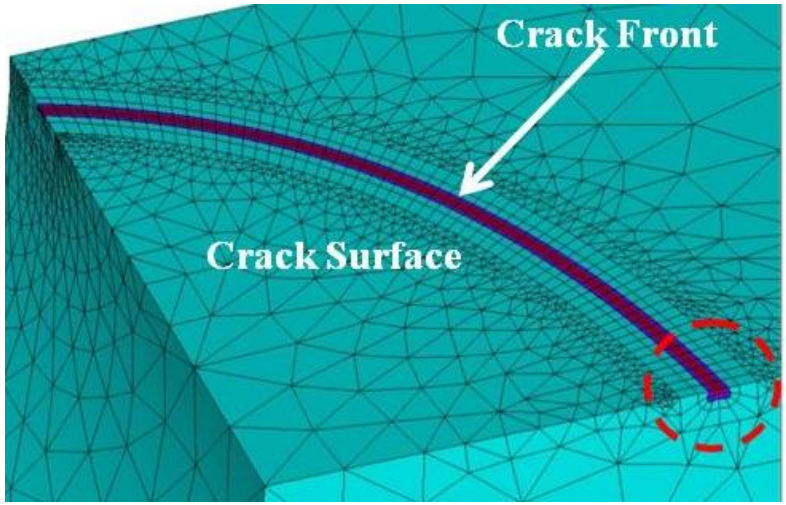
Double Symmetric Finite Element Model of Multiple Crack Specimen

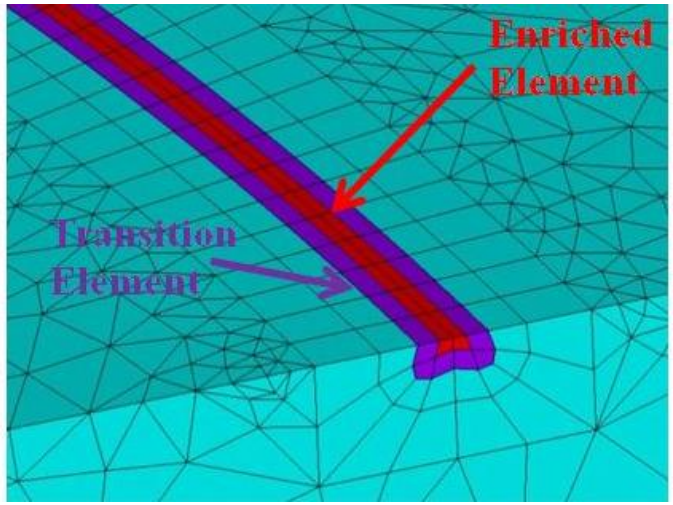
Nishimura, T., Noguchi, Y., and Uchimoto, T., "Damage Tolerance Analysis of Multiple-Site Cracks Emanating from Hole Array," Journal of Testing and Evaluation, JTEVA, Vol. 18, No. 6, Nov. 1990, pp. 401-407

Finite Element Fracture Models





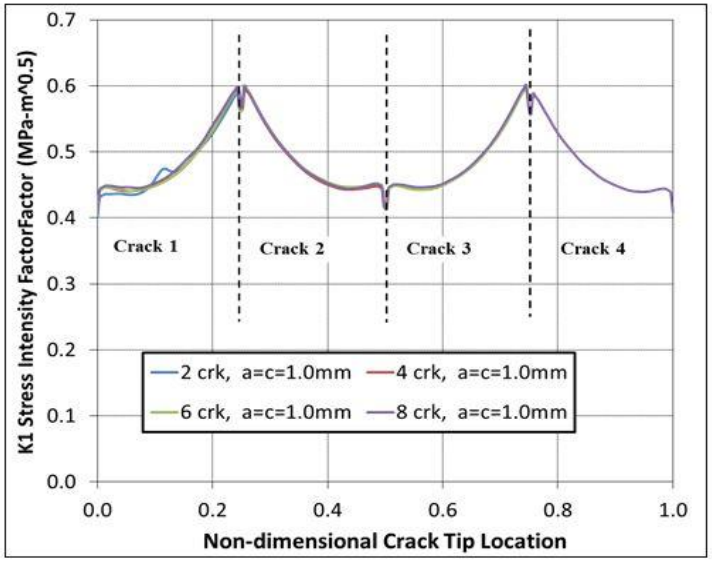




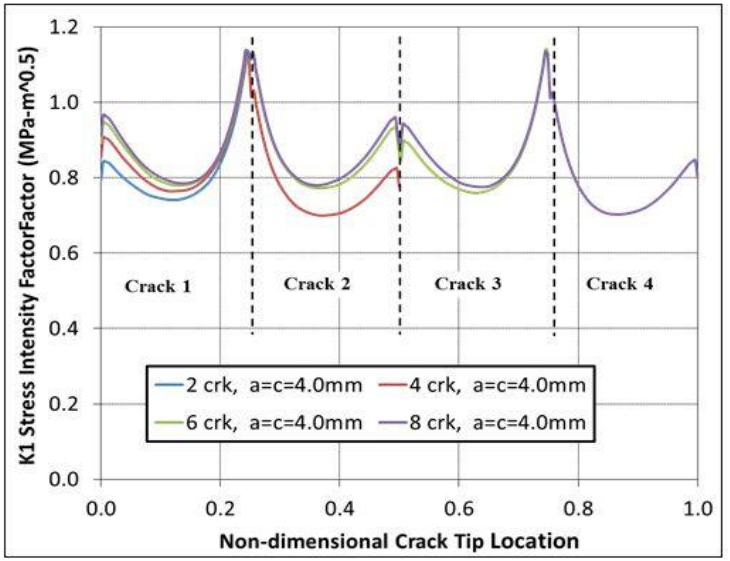
Finite Element Model of Multiple Crack Specimen

Analysis Results

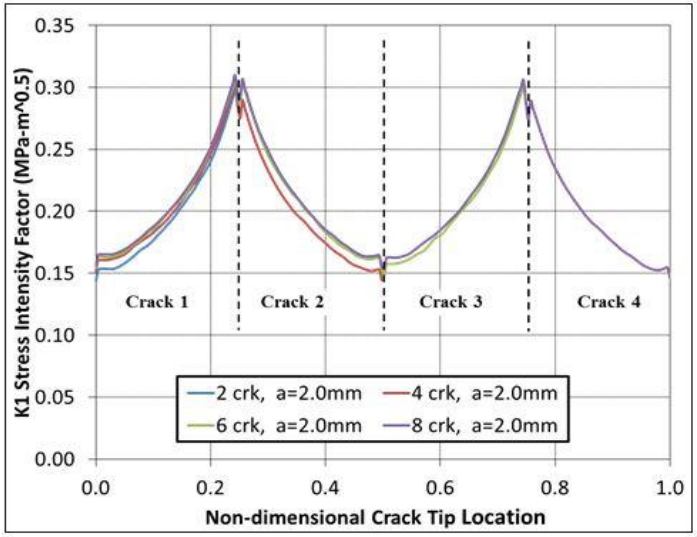
a=c=1 mm



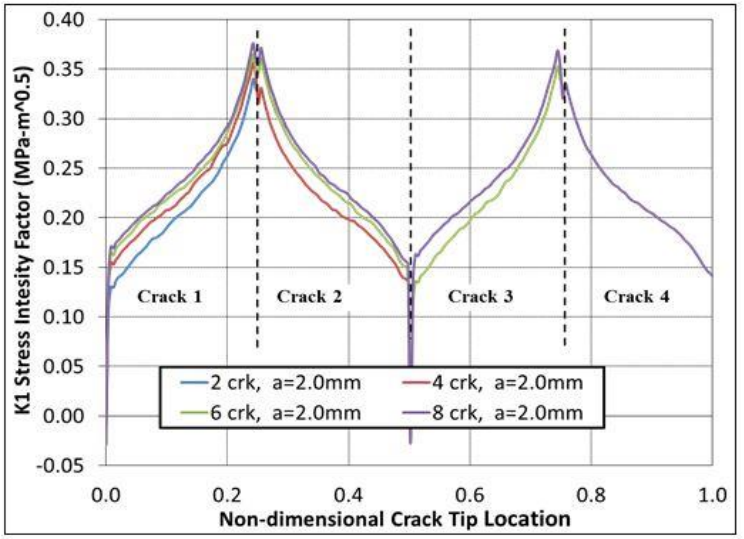
a=c=4 mm



a/c=2
a=2 mm

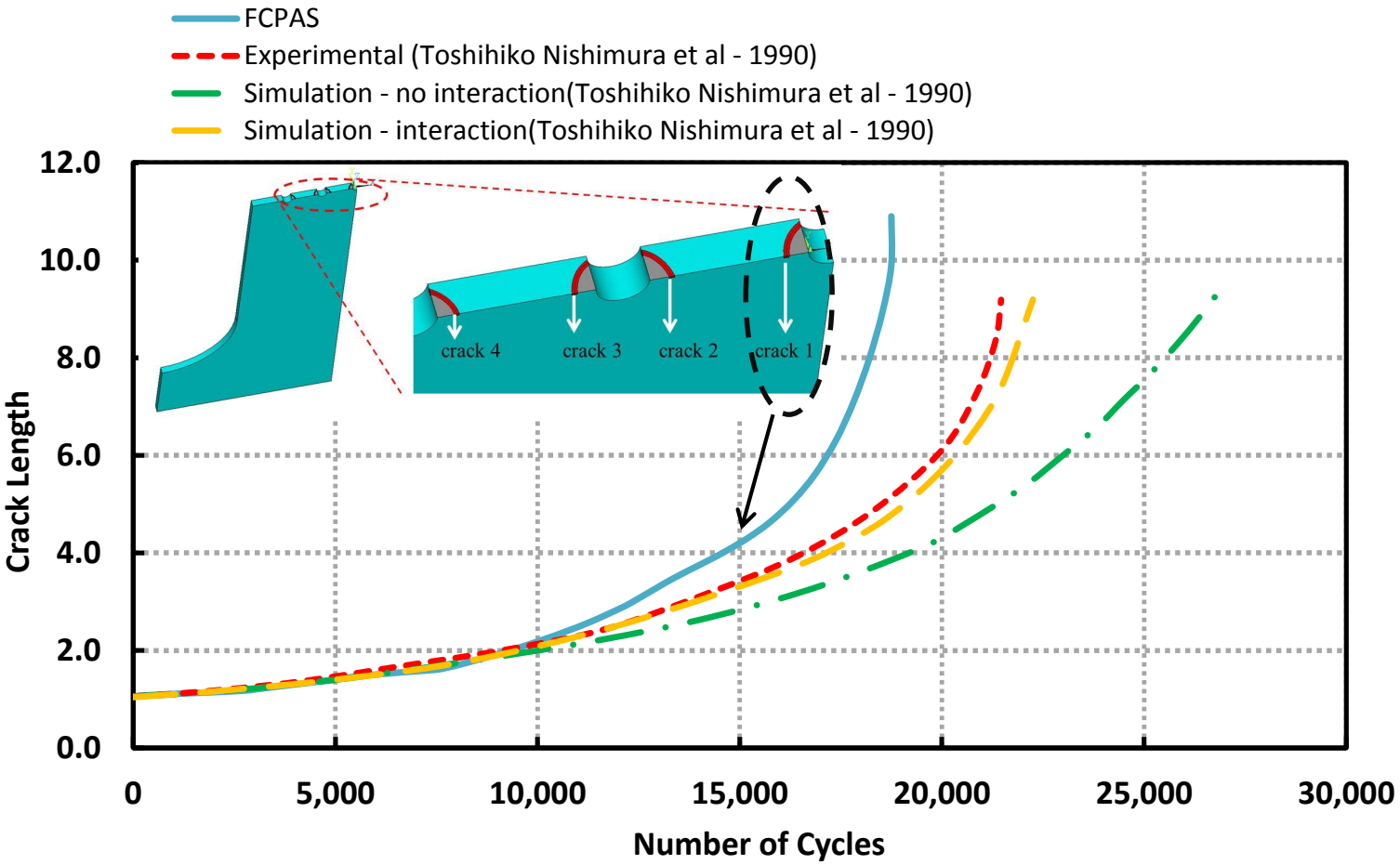


a/c=4
a=2 mm



Stress Intensity Factor Solutions of Interacting Multiple Cracks within FCPAS

Analysis Results

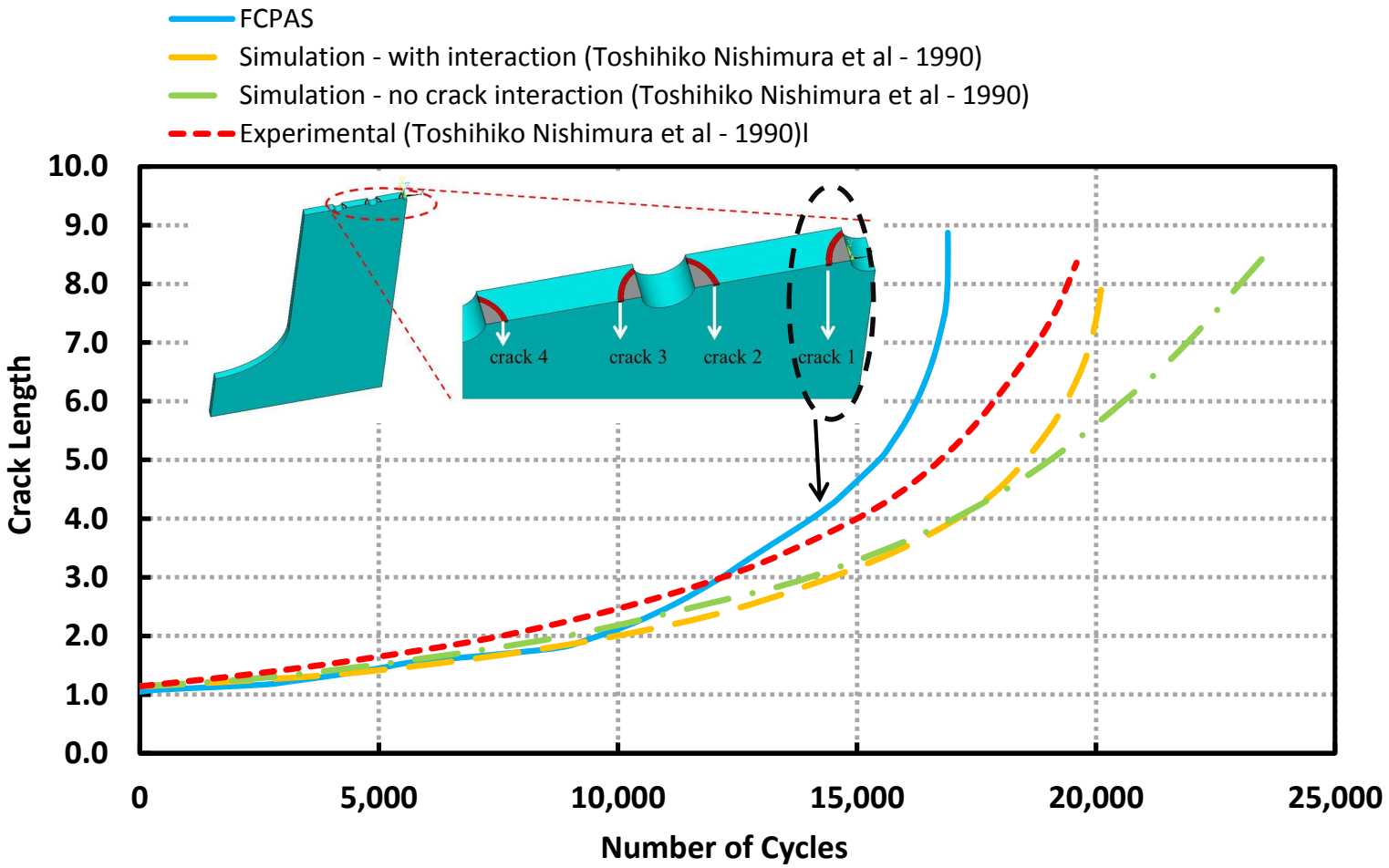


Life calculation comparison for 4-crack specimen (a-N data from 1st crack)

Life Calculation Results of Interacting Multiple Cracks From FCPAS Analyses

Nishimura, T., Noguchi, Y., and Uchimoto, T., "Damage Tolerance Analysis of Multiple-Site Cracks Emanating from Hole Array," Journal of Testing and Evaluation, JTEVA, Vol. 18, No. 6, Nov. 1990, pp. 401-407

Analysis Results

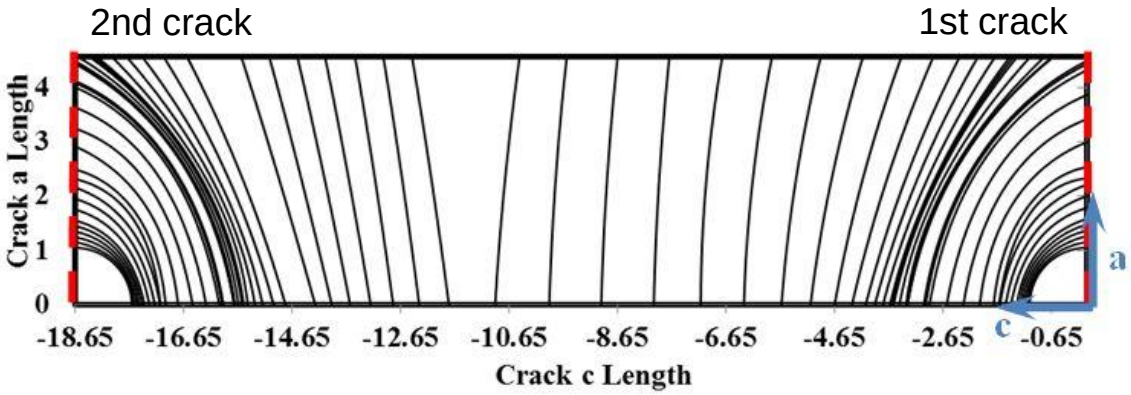


Life calculation comparison for 8-crack specimen (a-N data from 1st crack)

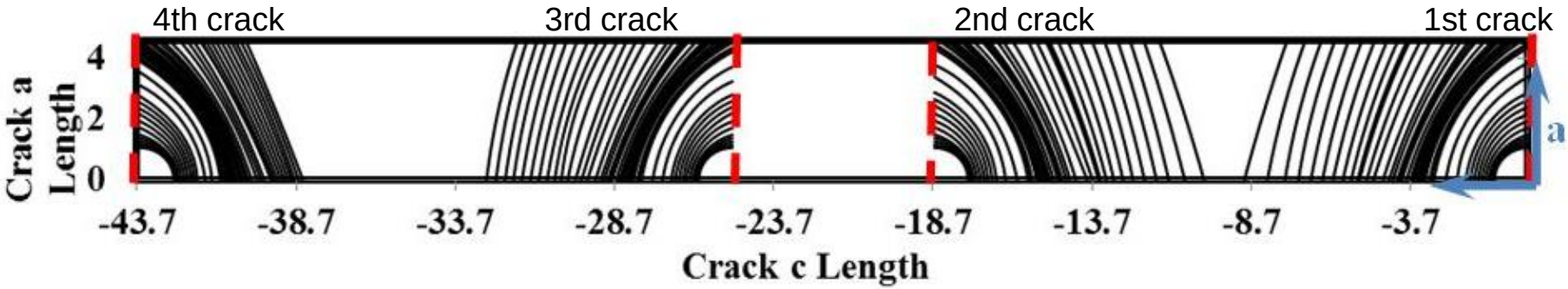
Life Calculation Results of Interacting Multiple Cracks From FCPAS Analyses

Nishimura, T., Noguchi, Y., and Uchimoto, T., "Damage Tolerance Analysis of Multiple-Site Cracks Emanating from Hole Array," Journal of Testing and Evaluation, JTEVA, Vol. 18, No. 6, Nov. 1990, pp. 401-407

Analysis Results



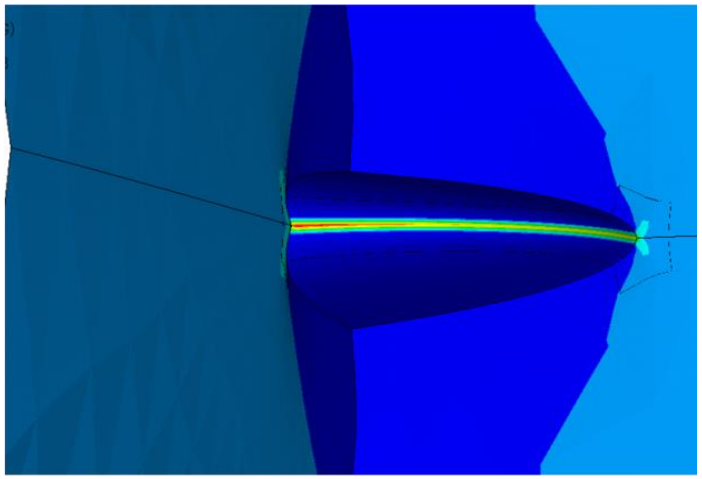
4-crack specimen crack profiles



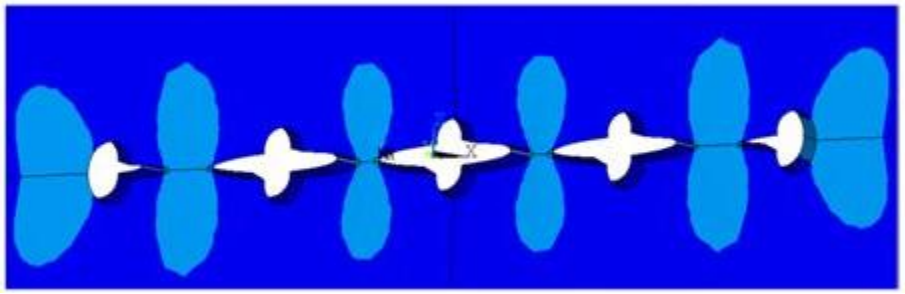
8-crack specimen crack profiles

Crack Profiles From Crack Propagation Analyses within FCPAS

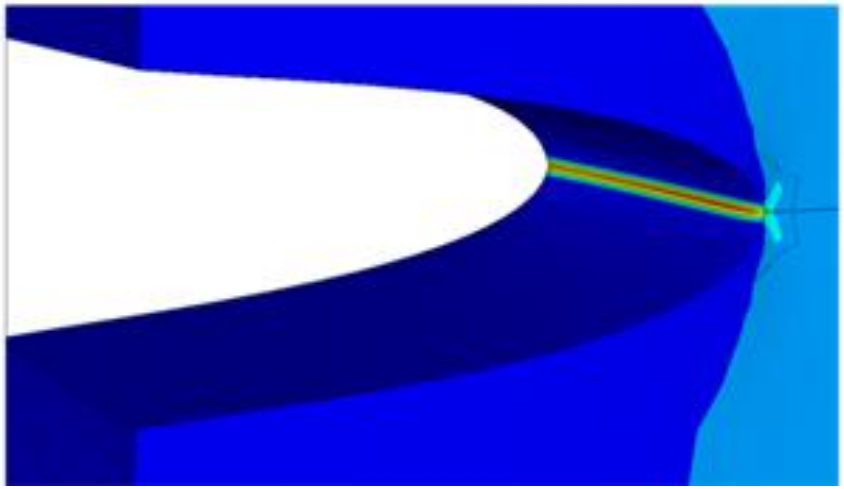
Displacements and Stress Contours



Corner Crack



8-crack specimen (through the thickness crack)



Close-up view of through the thickness crack

High Stresses Exist Along Crack Fronts

Summary and Conclusions

- FCPAS - Fracture and Crack Propagation Analysis System – is applied to variety of three-dimensional multiple fracture and crack propagation problems.
- Enriched finite elements used in FCPAS allow computation of SIFs and simulation of crack growth in three-dimensional multiple crack containing structures accurately and efficiently
  - ✓ No special mesh and post-processing needed
  - ✓ FCPAS (Fracture and Crack Propagation Analysis System) – currently automated multiple crack growth simulations in specimens under different loading and boundary conditions
- Fracture and Crack Propagation Analyses of Multiple Crack Containing Specimens and Attachment Lugs
  - ✓ FCPAS fracture models generated and Stress Intensity Factors (SIFs) are Computed
  - ✓ Life calculation results are obtained from FCPAS crack propagation analyses
  - ✓ Life Calculation Results agree well with literature results

Acknowledgements

✓*Authors are thankful to The Scientific and Technological Research Council of Turkey (TUBITAK) for the financial support during FCPAS Project.*