Fracture and Fatigue in Ansys

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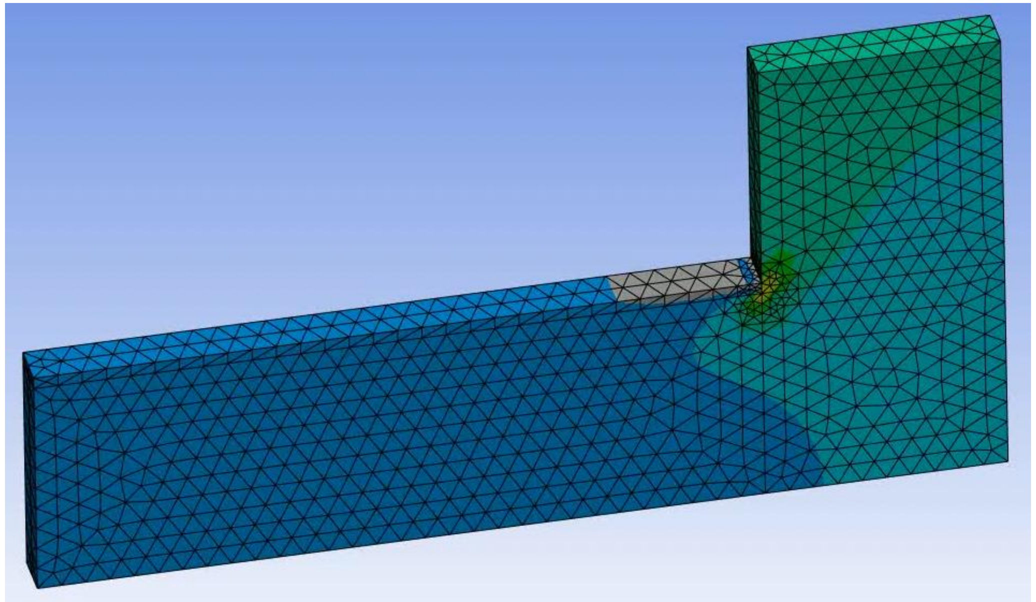
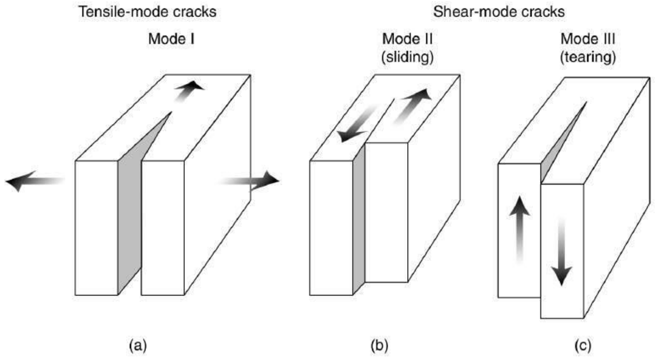
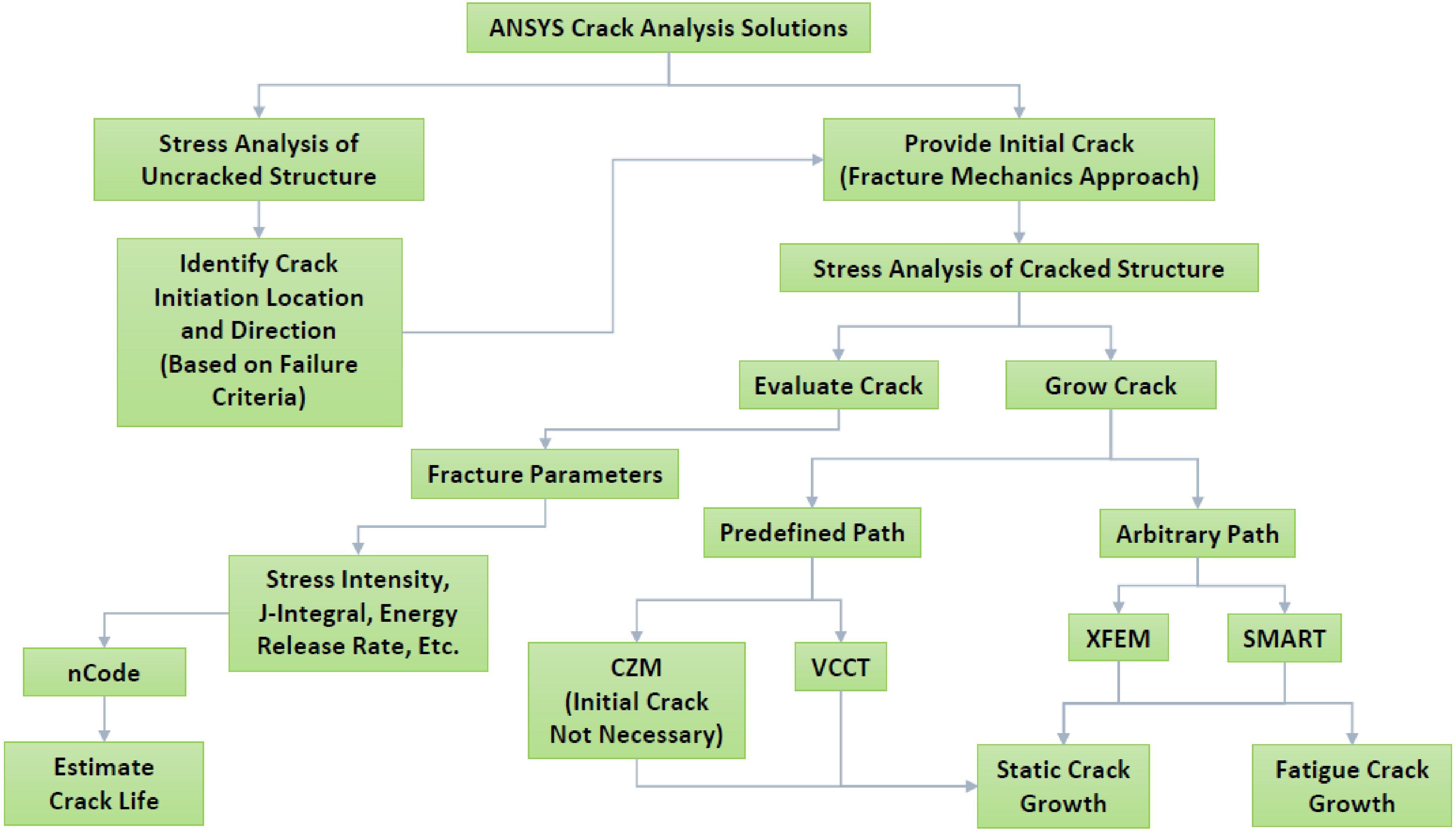
Agenda

- Overview
- Introduction Crack Growth Mechanics
- Virtual Crack Closure Technique
- Cohesive Zone Method
- eXtended Finite Element Method
- SMART Crack Method
- Demo





Overview of Capabilities



Introduction to Crack Growth Mechanics

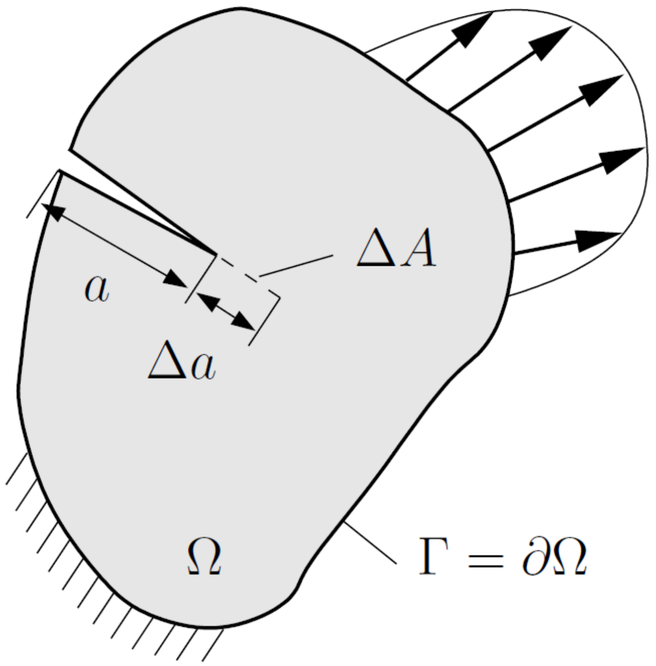
Overview:

Crack-growth simulation in homogeneous and composite structure is of interest because of the need for structural integrity assessments.

- Crack-growth is the separation process of two crack surfaces
- Most general approach: energy-release rate method
- A simple criterion based on the energy release rate can be expressed as:

$$G = G_c$$

- G_c is the critical fracture energy required to separate the two crack surfaces. J-Integral or Stress Intensity factors are typically used in a fracture criterion.

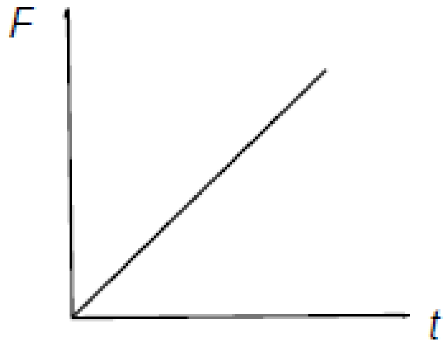


Introduction to Crack Growth Mechanics

Crack Growth Regimes

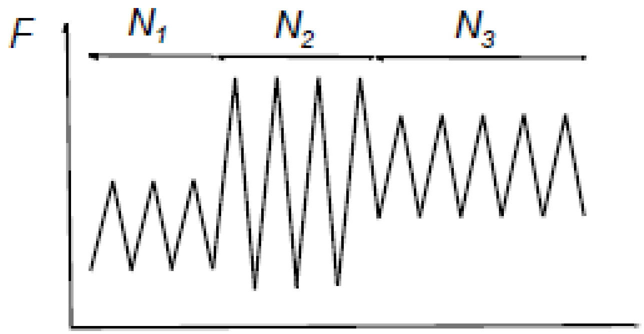
Static Crack Growth

Preexisting cracks may propagate when certain loading conditions are reached or when certain localized conditions are met.



Fatigue Crack Growth

In case when structures are subject to cyclic loading, it is of interest to know the interaction between crack extension rate and the number of load cycles.



Introduction to Crack Growth Mechanics

Crack Growth Regimes

Static Crack Growth

Two common fracture criteria for static crack-growth simulation and a crack will grow based on the user specified critical values of a given criterion:

- J-Integral: crack growth occurs when $J = J_c$
- Stress-intensity factor (SIF): crack growth occurs when $K_I = K_{IC}$

Note: When specifying J-integral as a fracture parameter, the crack is assumed to always grow along the initial direction. It is therefore suited for Mode I crack growth only

Introduction to Crack Growth Mechanics

Crack Growth Regimes

Fatigue Crack Growth

A typical fatigue crack-growth law formulates the crack-extension rate da/dN as function of stress-intensity factor K and stress ratio R:

$$\frac{da}{dN} = f(K, R)$$

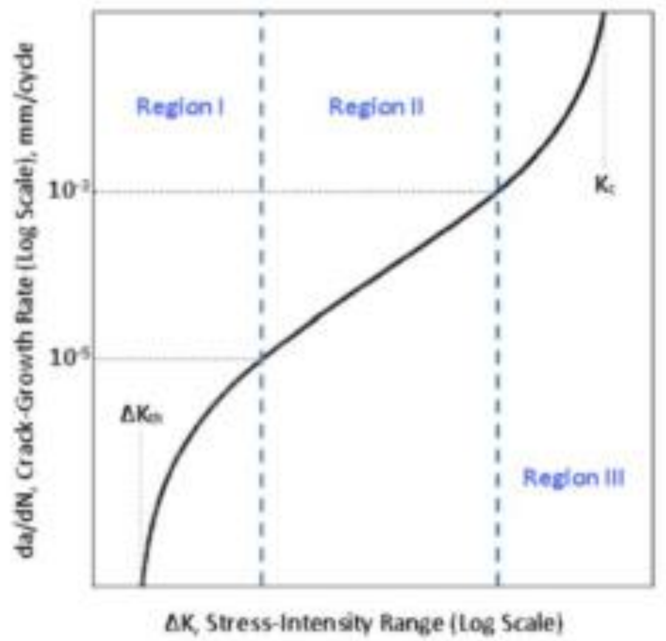
a - crack extension

N - fatigue cycle count

$\frac{da}{dN}$ - crack-growth rate per loading cycle due to fatigue

K - stress-intensity factor

R - stress ratio: $R = K_{min} / K_{max}$ (SIFs at minimum and maximum loads)



Crack Growth Simulation

- Predefined Path

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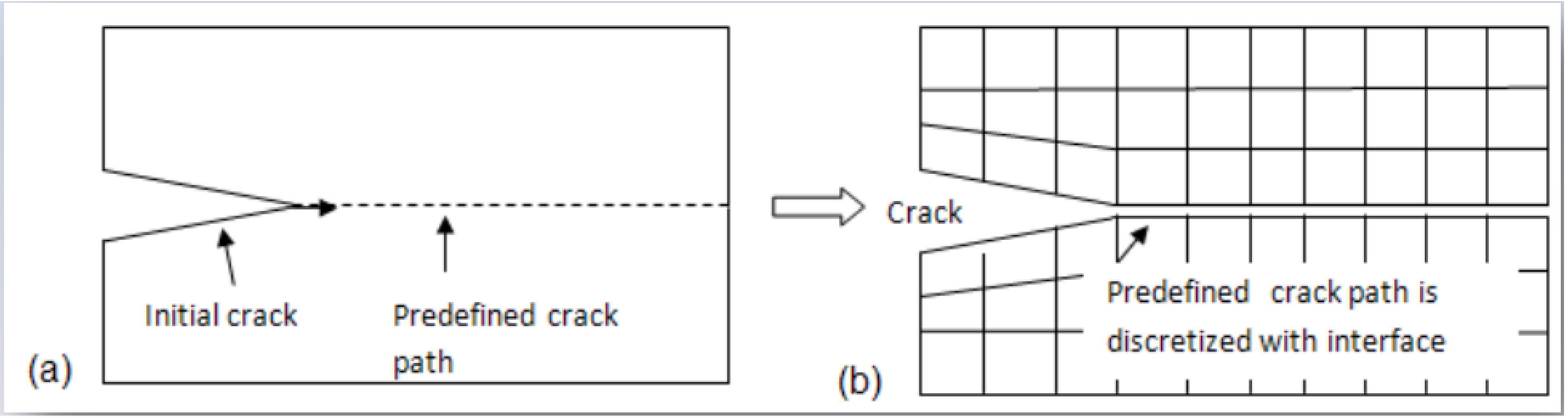
Virtual Crack Closure Technique (VCCT)

A common failure mode for composite structures is delamination (interface cracking), which can be characterized using the energy release rate calculated by the Virtual Crack Closure Technique (VCCT).

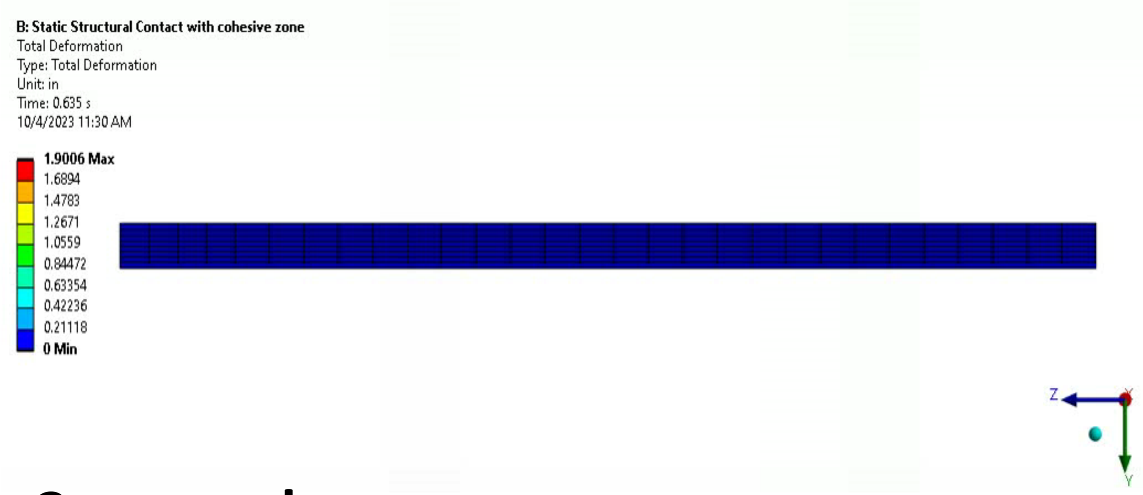
<u>VCCT is based on:</u>

- the assumption that the energy needed to separate a surface is the same as the energy needed to close the same surface and
- the assumptions of self-similar crack growth, i.e., that stress and displacement fields around the crack tip do not change significantly when the crack grows by a small amount.

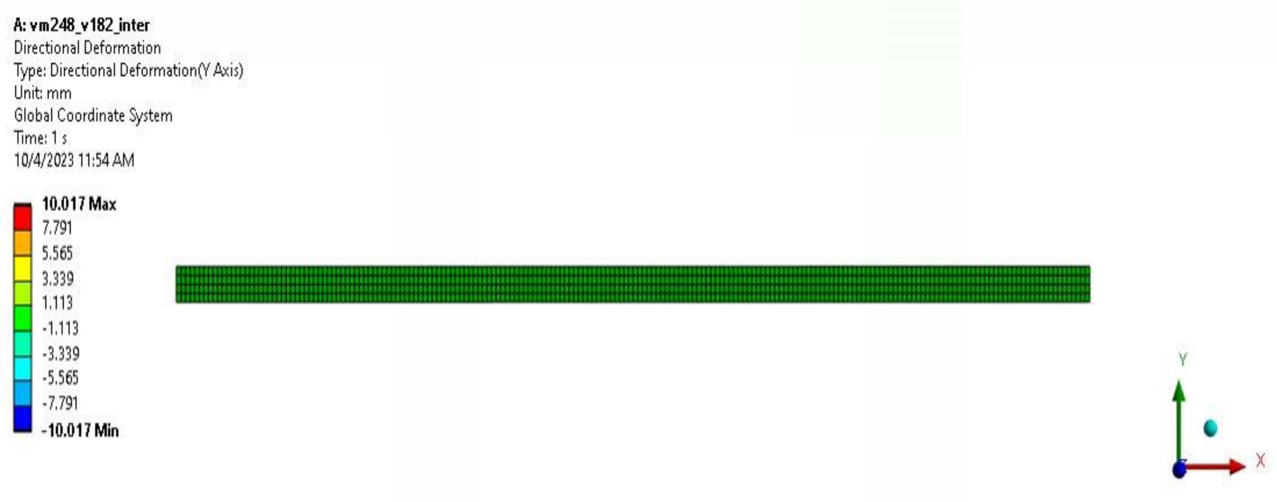


Cohesive Zone Method (CZM)

Fracture or delamination along an interface of the multi-phase materials. CZM model consists of a constitutive relation between the traction **T** acting on the interface and the corresponding interfacial separation **δ** . The definition of traction and separation depend on the element and material model.



Contact elements



Interface elements

Crack Growth Simulation

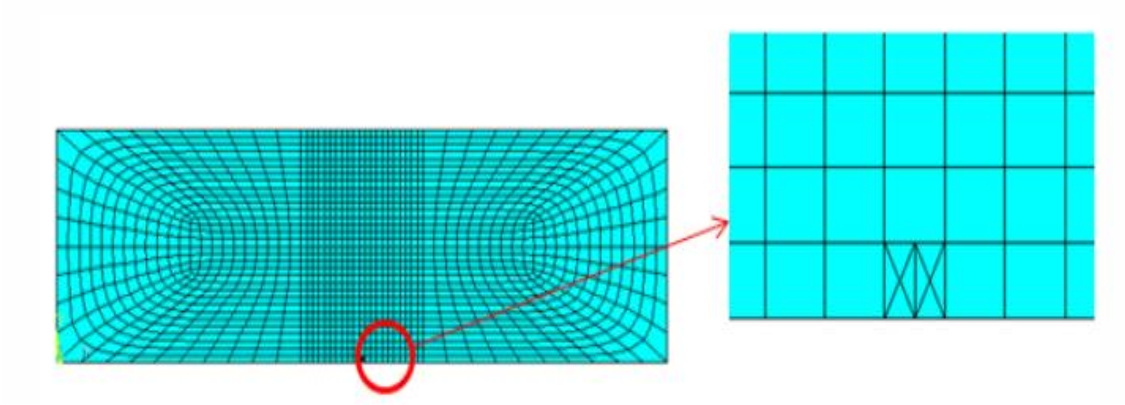
- Arbitrary Path

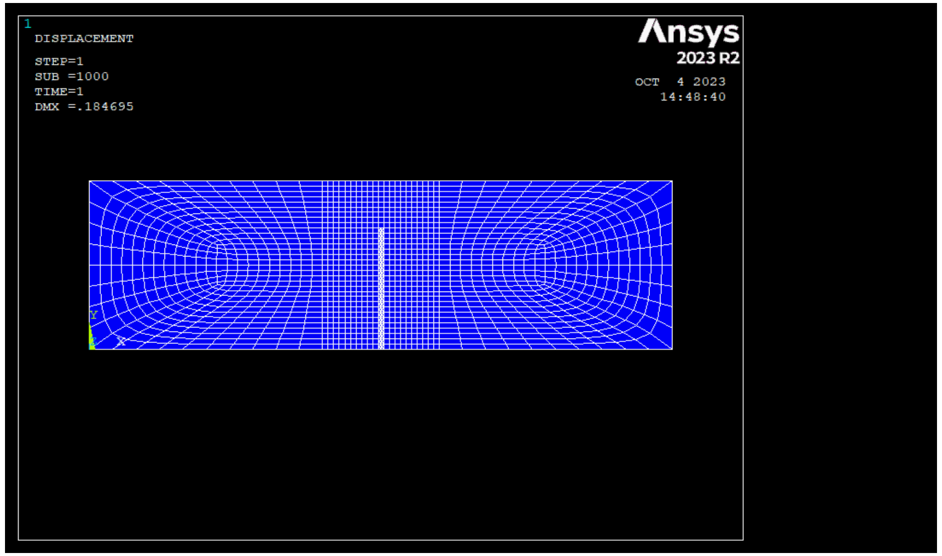
eXtended Finite Element Method (XFEM)

XFEM models cracks and other discontinuities by enriching the degrees of freedom in the model with additional displacement functions that accounts for the jump in displacement across the discontinuity.

<u>Features:</u>

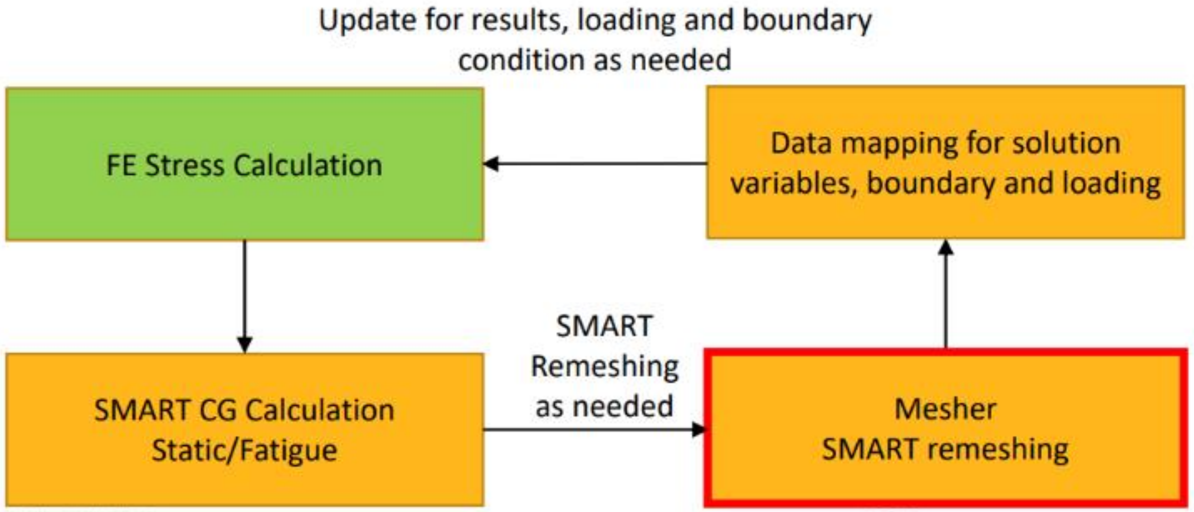
- Offers a way to model the cracks without explicitly meshing the crack surfaces.
- For growing cracks, the method assumes that the discontinuities cut the element fully.
- As the crack grows, newly introduced crack segments are assumed to have cohesive zone behavior.

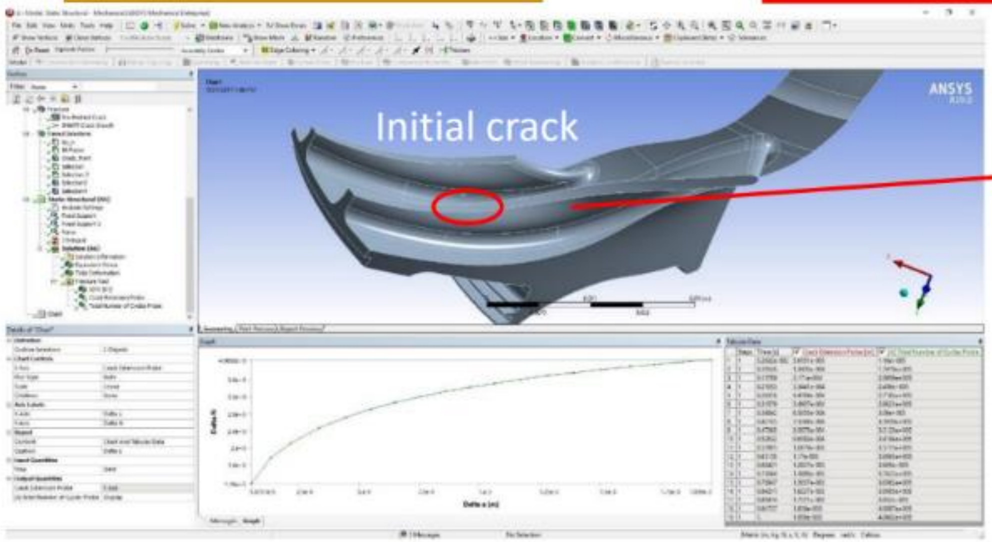


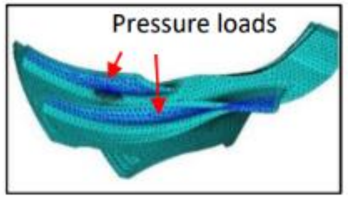


Ansys SMART Crack Growth

SMART Framework







SMART crack growth simulation framework – resolution to the challenges

- **SMART stands for Separating, Morphing, Adaptive and Remeshing Technology**
  - Integrates morphing, adaptive and remeshing technology into FEA **solver solution kernel – substep level**
  - Remeshing only local to crack front region
  - Meshing update due to crack growth is automatic
- Effective distributed solution scheme and solver support for large scale and real-world simulation
- Innovative crack initiation identification method

  ……

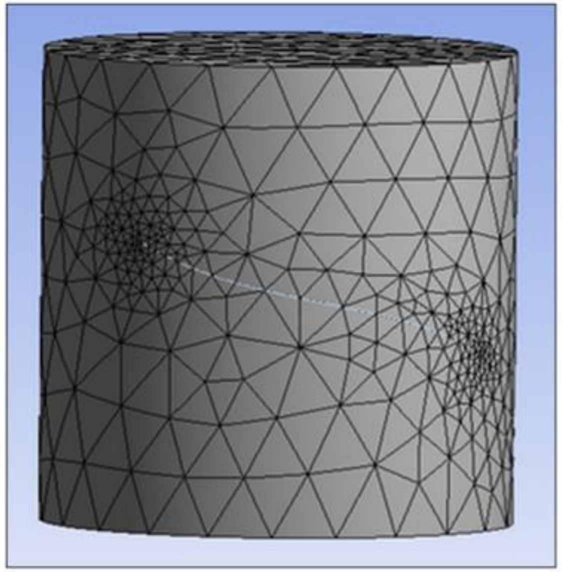
- **End-to-end solution workflow in WB Mechanical**

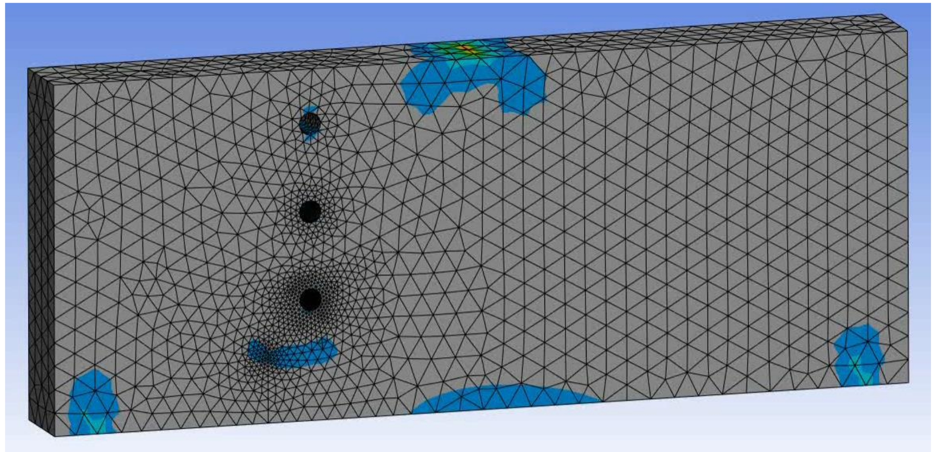
  Automatic, seamless, robust, effective

Ansys SMART Crack Growth

Summary

- Homogeneous and isotropic linear elastic material
- Mixed mode crack growth
  - Mixed mode fracture based on maximum tangential stress assumption
- Tet element based remeshing
- Supports multiple cracks
- Static crack growth with J-integral and SIFs
- Fatigue crack growth with FCG laws
- Crack growth arrest
- Automatic crack initiation
- Contact support (Outside remeshing region)
- CZM element support
- Supports non-proportional loading





Insert a crack in a geometry/mesh

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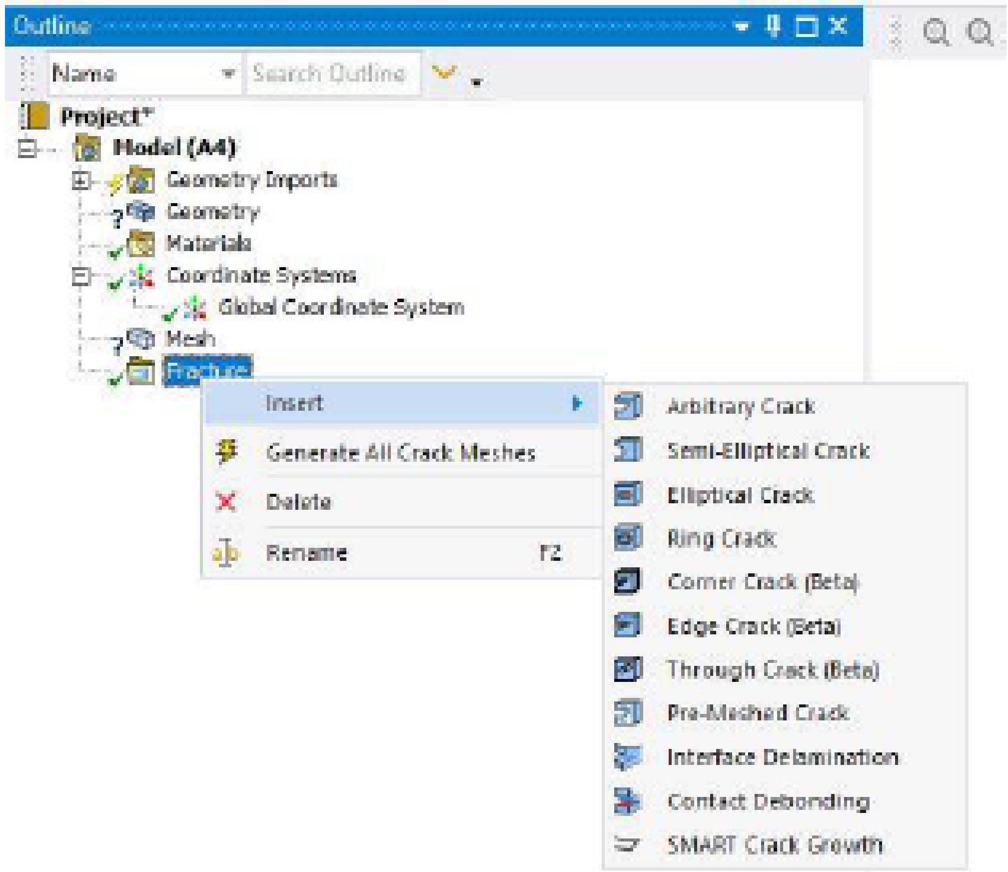
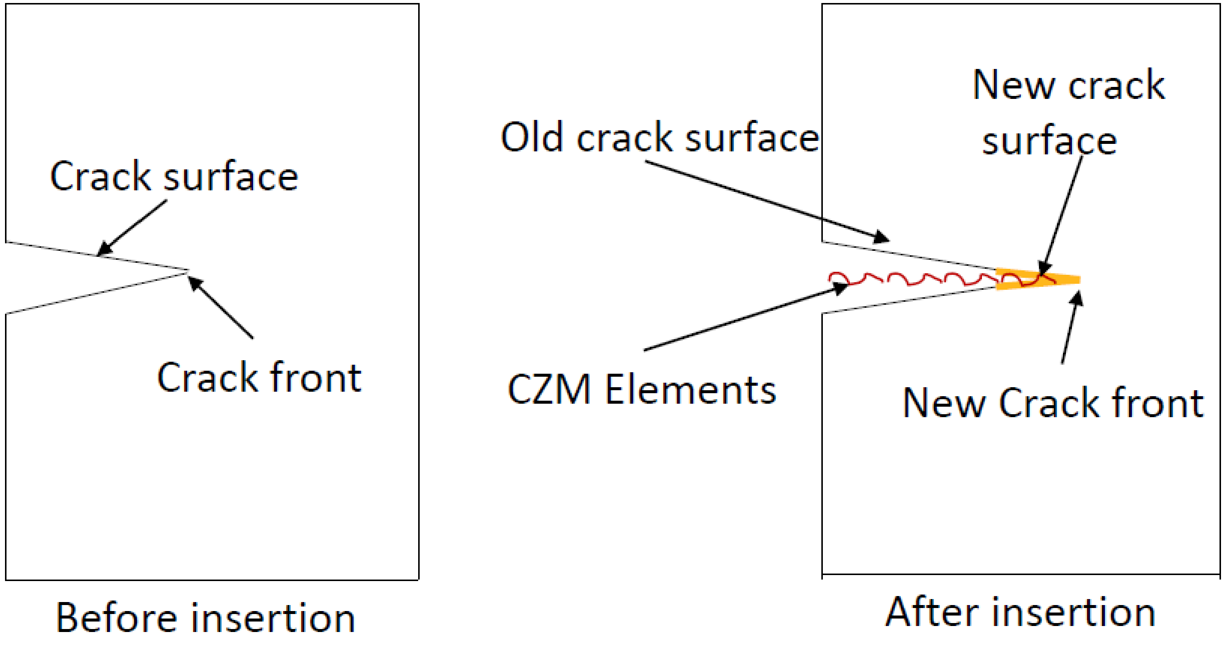


- Arbitrary crack
- Semi-elliptical crack
- Elliptical crack
- Ring crack
- Corner crack (Beta)
- Edge crack (Beta)
- Through crack (Beta)
- Pre-meshed crack

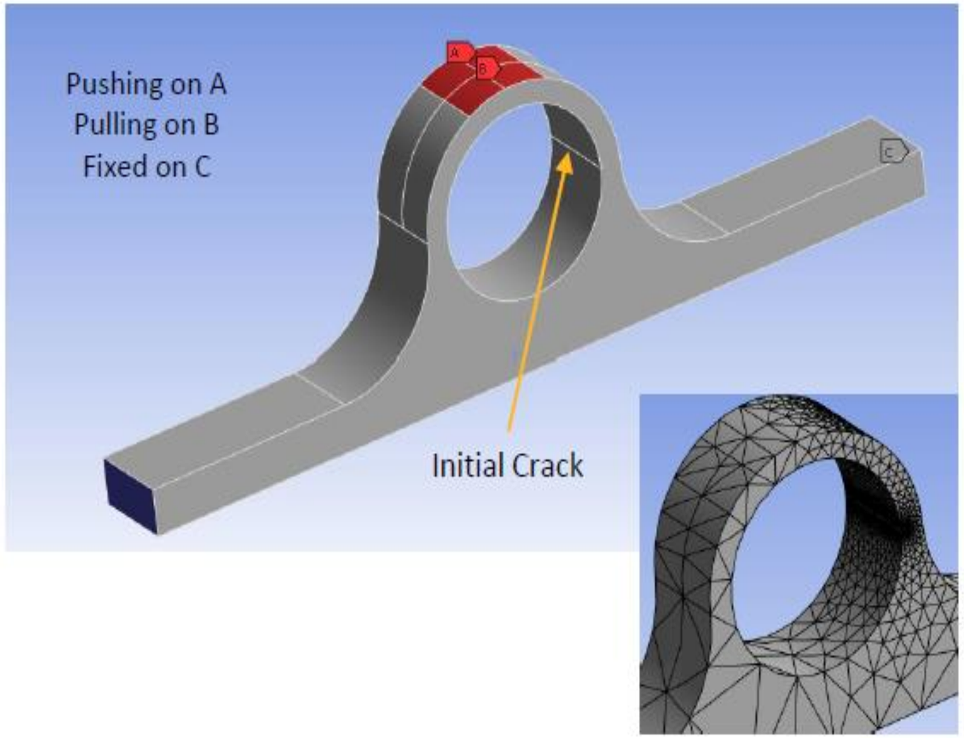
SMART with Cohesive Zone Modeling

SMART crack growth with automatically inserting of interface element (INTER204)

- Interface elements for initial crack surfaces
- Interface elements for new crack surfaces
- **Prevents penetration of crack surfaces under compression**



Crack Growth under asymmetric loadings



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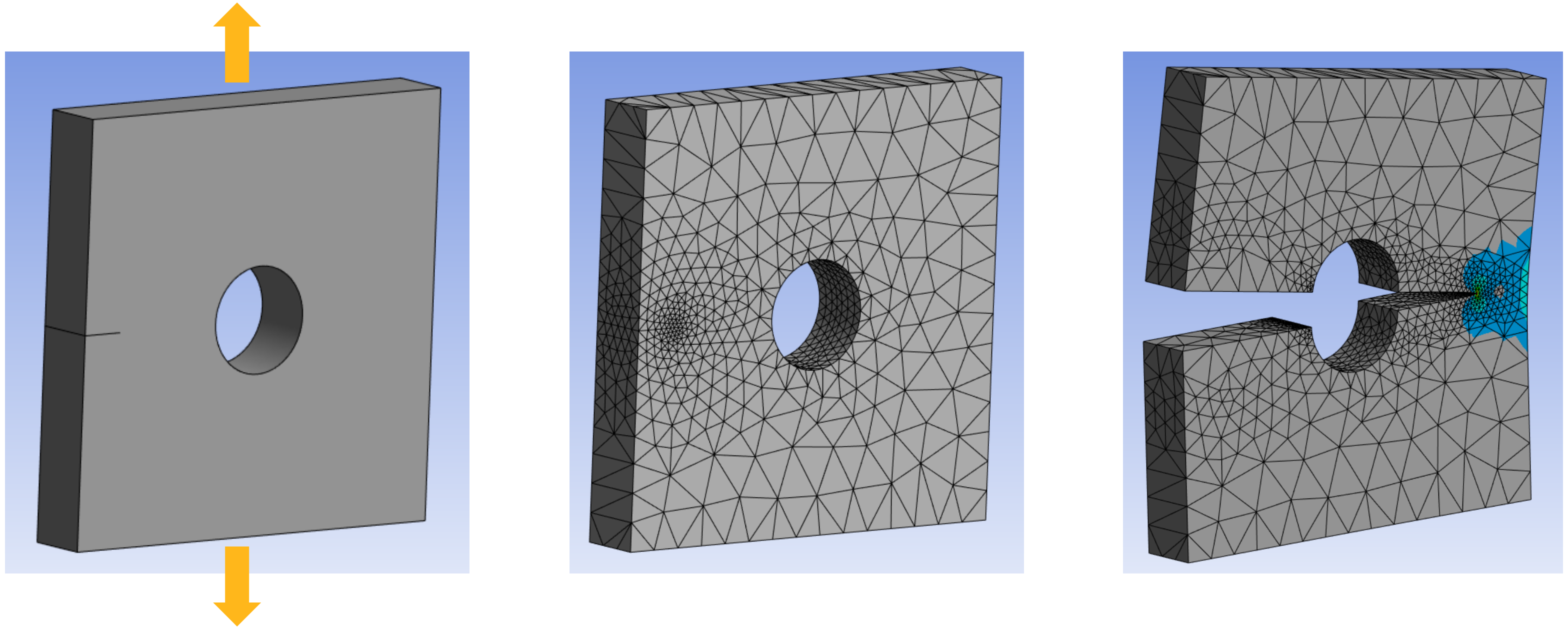
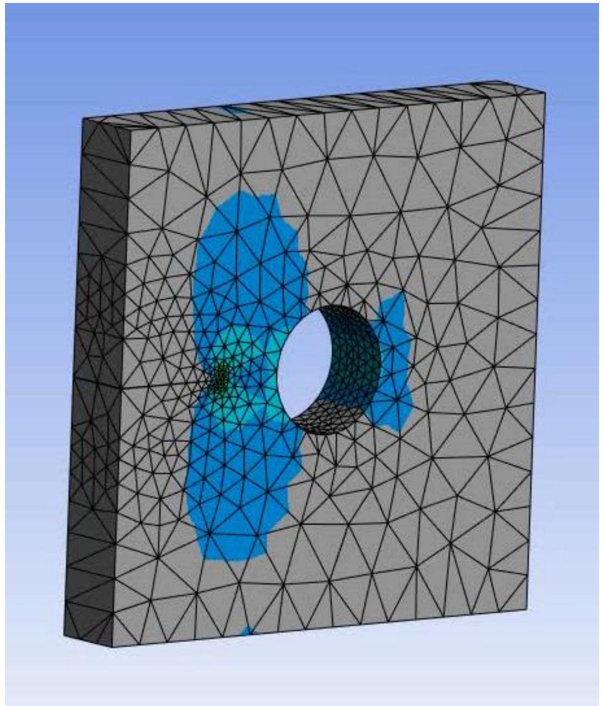
Adaptive Crack Initiation

Adaptive crack initiation procedure

- Based on modern statistical data analysis technologies
- Initiation sites are defined by user defined via command
- Initial crack sizes are user defined
- Principal stress criterion is used



Initial crack propagates into the hole, new crack is then initiated after initial crack growing into the hole and propagates further.



Demo

SMART – Crack closure models

SMART – fatigue crack growth

Crack growth rate model
(Paris/Tabular fatigue law)

+

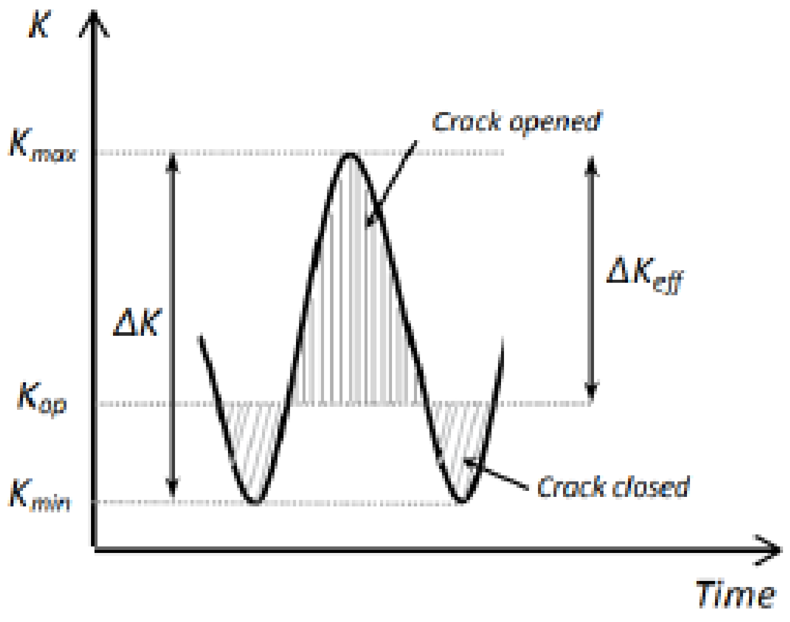
Crack-closure model
[optional]

Measure of crack-closure

$$U = \frac{\Delta K_{eff}}{\Delta K}$$

$$\frac{da}{dN} = g(\Delta K_{eff}) = g(U\Delta K)$$

Fatigue crack closure models	
Elber function	$U = 0.5 + 0.4R$
Schijve function	$U = 0.55 + 0.33R + 0.12R^2$
Newman function	$U = \frac{1 - f(R)}{1 - R}$ *f(R)* is Newman crack opening function
Polynomial function	$U = A_0 + A_1 R + .. + A_n R^n$



$$R = \frac{K_{min}}{K_{max}}$$ stress ratio

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