Modeling Fracture and Failure with Abaqus

Damage and failure for ductile metals

Introduction

Fracture and failure modeling allows for product designs that maximize the safe operating life of structural components. Abaqus offers many capabilities that enable fracture and failure modeling.

Damage and failure for ductile metals

Introduction

- Proper modeling techniques for capturing crack-tip singularities in fracture mechanics problems
- Proper modeling techniques for finite-strain (nonlinear) fracture mechanics problems
- Using Abaqus/CAE to create meshes appropriate for fracture studies
- Calculation of stress intensity factors and contour integrals around a crack tip
- Material damage and failure models
- Wear and erosion modeling
- Simulating crack growth using cohesive elements
- Simulating crack growth using VCCT for Abaqus

Fracture mechanics: overview

ABAQUS/Standard provides the following methods for performing fracture mechanics studies:

- Onset of cracking: The onset of cracking can be studied in quasi-static problems by using contour integrals. The J-integral, the C_t-integral (for creep), the stress intensity factors for both homogeneous materials and interfacial cracks, the crack propagation direction, and the T-stress are calculated by ABAQUS/Standard. Contour integrals can be used in two- or three-dimensional problems. In these types of problems focused meshes are generally required and the propagation of a crack is not studied.

Fracture mechanics: overview

- Crack propagation: The crack propagation capability allows quasi-static crack growth along predefined paths to be studied in two-dimensional cases. Cracks debond along user-defined surfaces. Three crack propagation criteria are available, and multiple cracks can be included in the analysis. Contour integrals can be requested in crack propagation problems.

- Line spring elements: Part-through cracks in shells can be modeled inexpensively by using line spring elements in a static procedure.

Contour integral evaluation

Abaqus/Standard offers the evaluation of several parameters for fracture mechanics studies:

- the J-integral, which is widely accepted as a quasi-static fracture mechanics parameter for linear material response and, with limitations, for nonlinear material response;

- the C_t-integral, which has an equivalent role to the J-integral in the context of time-dependent creep behavior in a quasi-static step.

- the stress intensity factors, which are used in linear elastic fracture mechanics to measure the strength of the local crack-tip fields.

Contour integral evaluation

- the crack propagation direction-i.e., the angle at which a preexisting crack will propagate.

- the T-stress, which represents a stress parallel to the crack faces and is used as an indicator of the extent to which parameters like the J-integral are useful characterizations of the deformation field around the crack.

Abaqus/CAE Usage:

Interaction module: **Special** → **Crack** → **Create**: **Name:** *crack name*

Step module: history output request editor: **Domain: Contour integral name**: *crack name*, **Number of contours:** *n*, **Type:** *integral_type*

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Defining the data required for a contour integral

Defining the crack front:

Abaqus/CAE Usage:

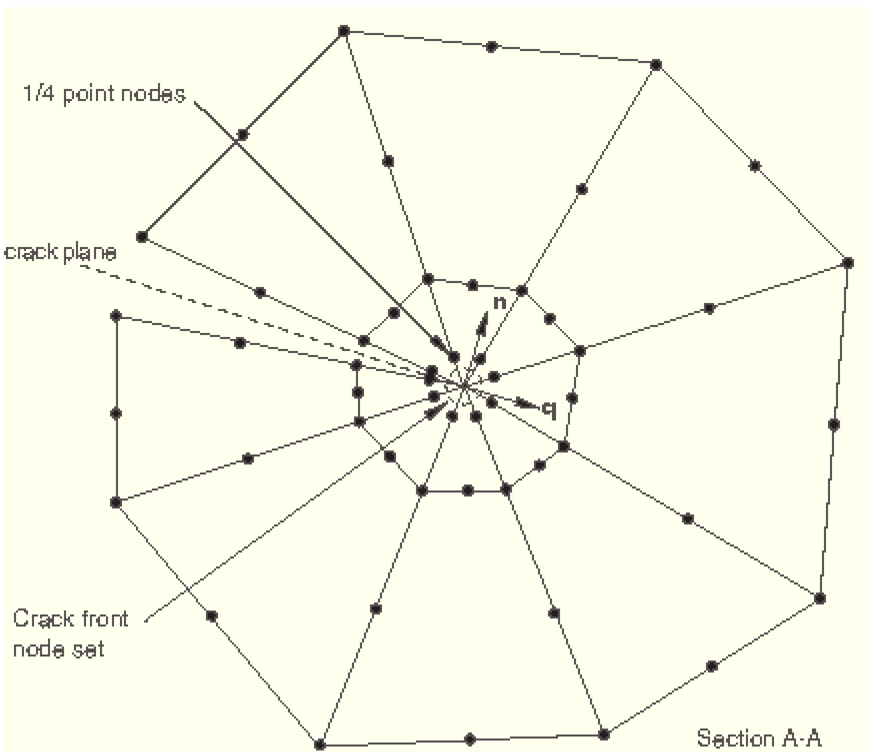
Interaction module: **Special** → **Crack** → **Create**: *select the crack front, then select the crack tip (in two dimensions) or crack line (in three dimensions)*

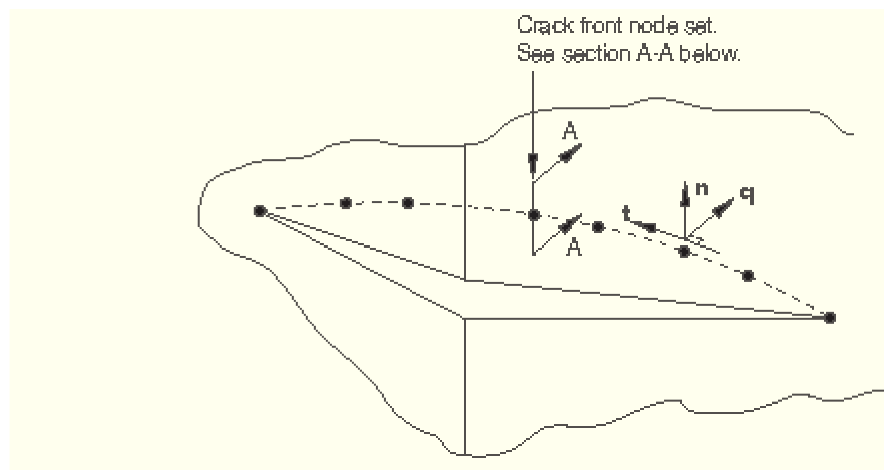
Abaqus/CAE Usage:

Interaction module: **Special** → **Crack** → **Create**: *select the crack front:* **Specify crack extension direction using: q vectors**

Defining the data required for a contour integral

Defining the crack front:

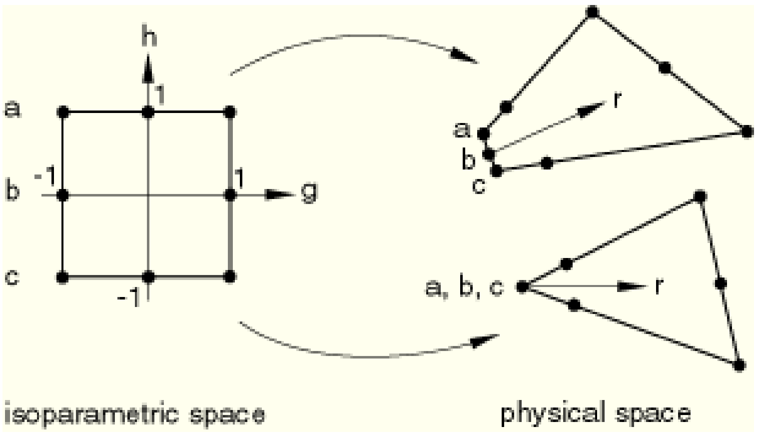




Contour integral evaluation

Creating the singularity:

$$\begin{aligned} &\varepsilon \propto r^{-1/2} && \text{for linear elasticity,} \\ &\varepsilon \propto r^{-1} && \text{for perfect plasticity, and} \\ &\varepsilon \propto r^{-\frac{n}{n+1}} && \text{for power-law hardening.} \end{aligned}$$



$$\varepsilon \to \frac{A}{r} + \frac{B}{r^{1/2}} \quad \text{as} \quad r \to 0.$$

Creating a square root singularity:(suitable for linear elasticity).

Abaqus/CAE Usage:

Interaction module: **Special** → **Crack** → **Create**: *select the crack front and crack tip, and specify the crack extension direction:* ***Singularity****:* ***Midside node parameter:*** *n*, ***Collapsed element side, single node***

Contour integral evaluation

Creating the singularity:

$$\begin{aligned}
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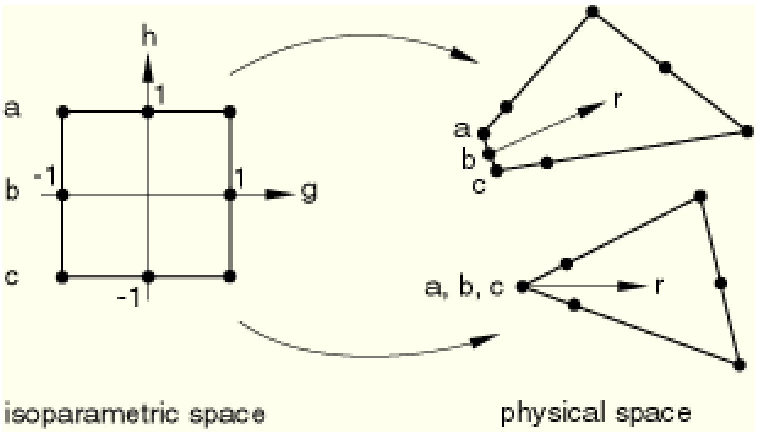


$$\varepsilon \to \frac{A}{r} + \frac{B}{r^{1/2}} \quad \text{as} \quad r \to 0.$$

Creating a 1/r singularity:(suitable for perfect plasticity).

Abaqus/CAE Usage:

Interaction module: **Special** → **Crack** → **Create**: *select the crack front and crack tip, and specify the crack extension direction:* ***Singularity**: **Midside node parameter:** n**, **Collapsed element side, duplicate nodes***

Crack propagation analysis

Crack propagation analysis:

- allows for five types of fracture criteria—critical stress at a certain distance ahead of the crack tip, critical crack opening displacement, crack length versus time, VCCT (the Virtual Crack Closure Technique), and the low-cycle fatigue criterion based on the Paris law.

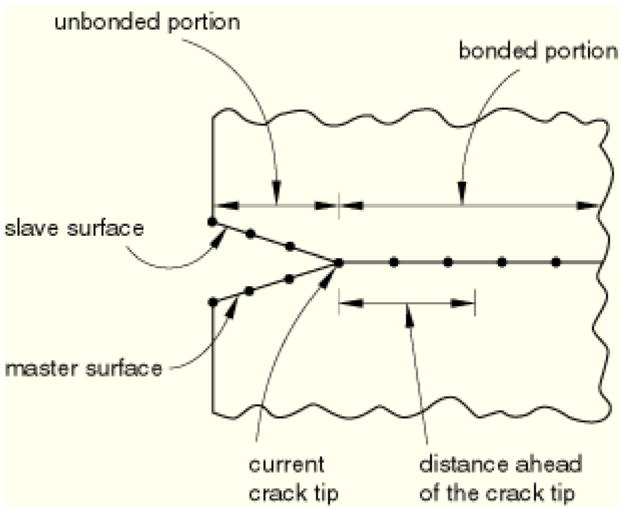
- models quasi-static crack growth in two dimensions (planar and axisymmetric) for all types of fracture criteria and in three dimensions (solid, shells, and continuum shells) for VCCT and the low-cycle fatigue criteria

- requires that you define two distinct initially bonded contact surfaces between which the crack will propagate.

Crack propagation analysis

Critical stress criterion:

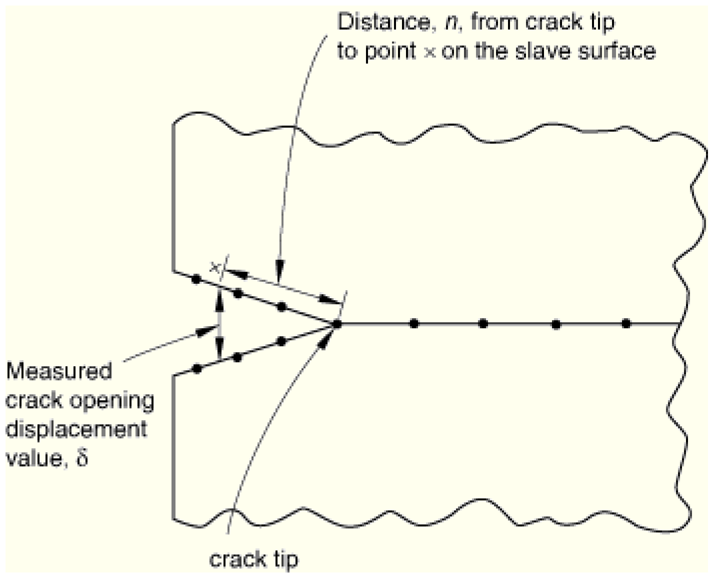
$$f = \sqrt{\left(\frac{\hat{\sigma}_n}{\sigma^f}\right)^2 + \left(\frac{\tau_1}{\tau_1^f}\right)^2 + \left(\frac{\tau_2}{\tau_2^f}\right)^2}, \quad \hat{\sigma}_n = \max(\sigma_n, 0),$$



Distance specification for the critical stress criterion

Crack propagation analysis

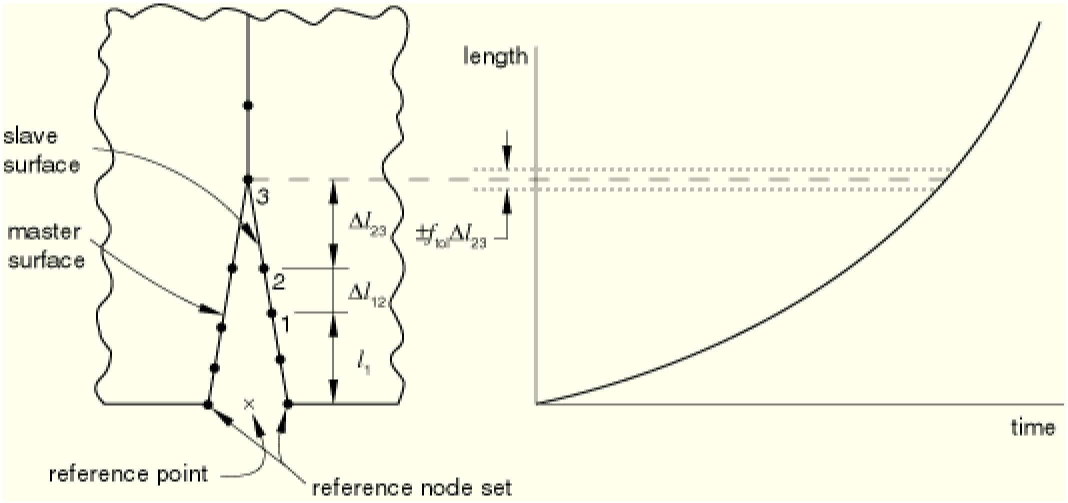
Critical crack opening displacement criterion:



Distance specification for the critical crack opening displacement criterion

Crack propagation analysis

Crack length versus time criterion:



Crack propagation as a function of time

The fracture criterion, f, is given by $$f = \frac{l - (l_3 - \Delta l_{23})}{\Delta l_{23}},$$

Crack propagation analysis

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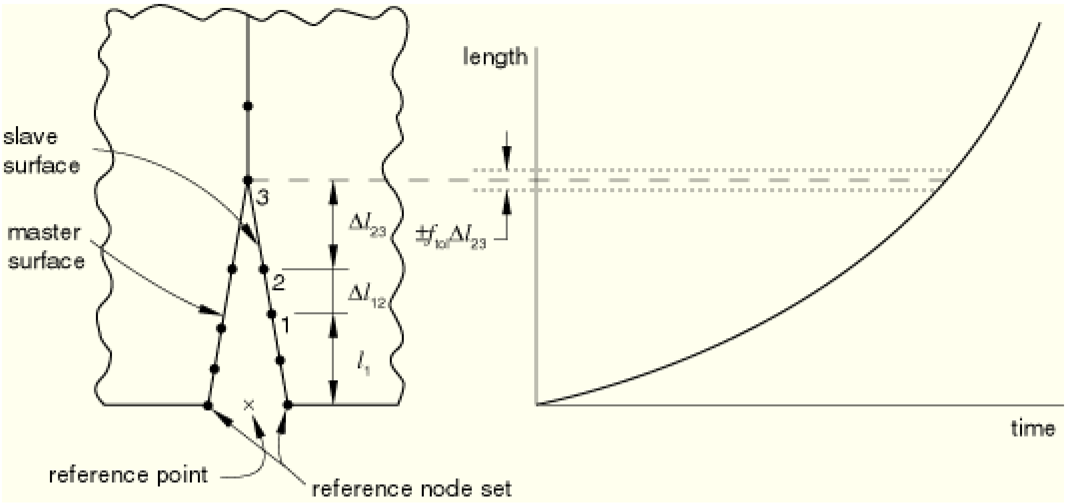

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