Damage and failure for ductile metals

Damage and failure for ductile metals

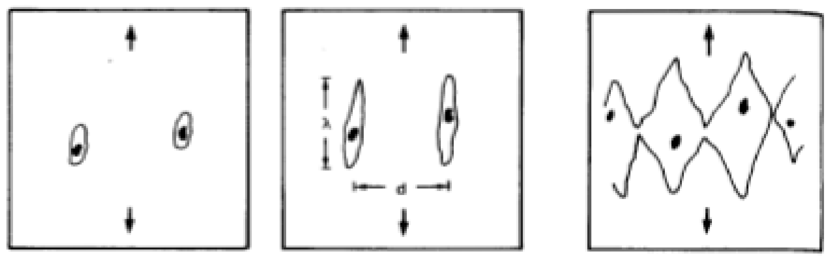
Introduction

Abaqus/Standard and Abaqus/Explicit offer a general capability for predicting the onset of failure, and Abaqus/Explicit offers a capability for modeling progressive damage and failure of ductile metals.

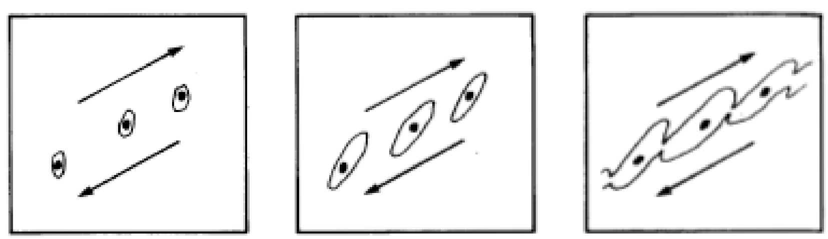
Damages in a structure are caused by material degradation due to initiation, growth and coalescence of mirco-cracks/voids in a 'real-life' material element from monotonic, cyclic/fatigue, thermo-mechanical loading or dynamic/explosive impact loading.

Introduction

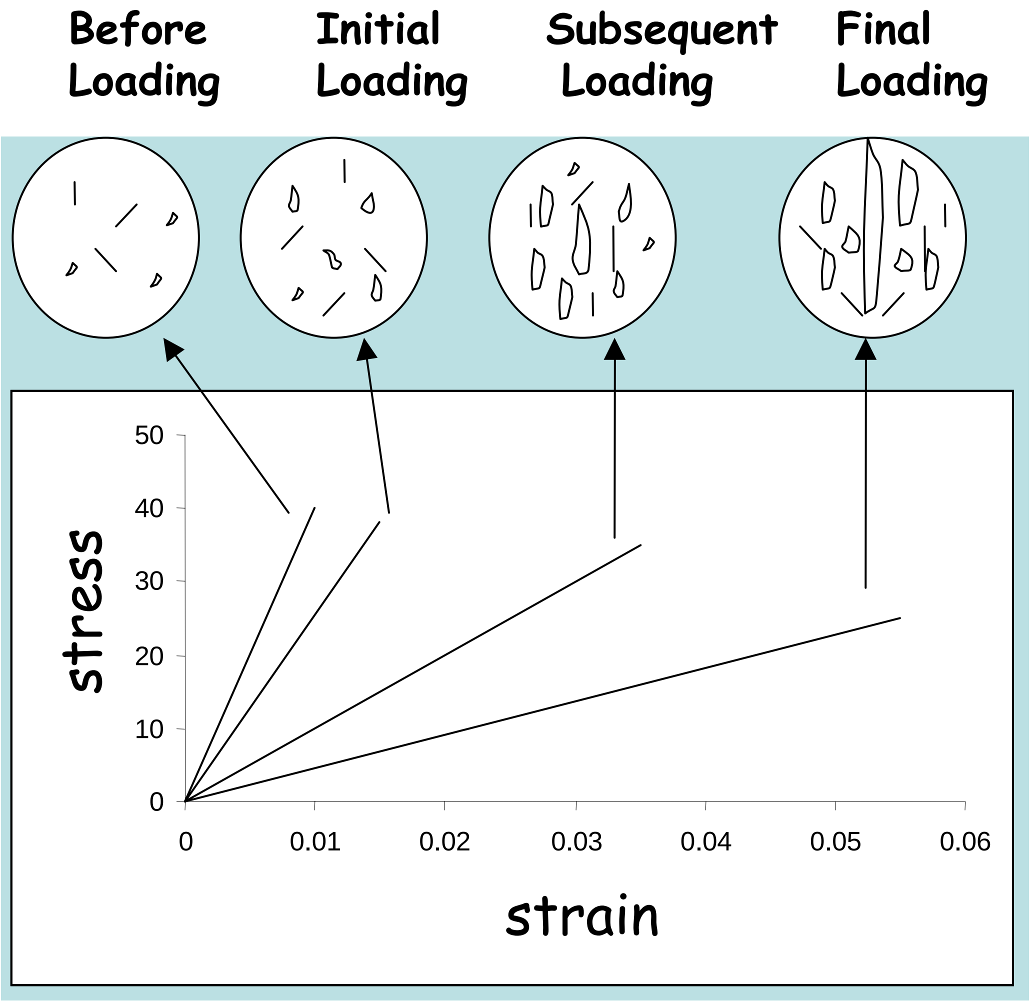
FORMATION OF ELONGATED VOIDS/CRACKS AT INCLUSIONS AND NECKING OF THE LIGAMENTS BETWEEN VOIDS



LOCALIZED NECKING/CRACK FORMATIOIN DUE TO SHEAR BY LINKING UP OF VOIDS FORMED AROUND INCLUSIONS



Introduction



Damage Mechanics

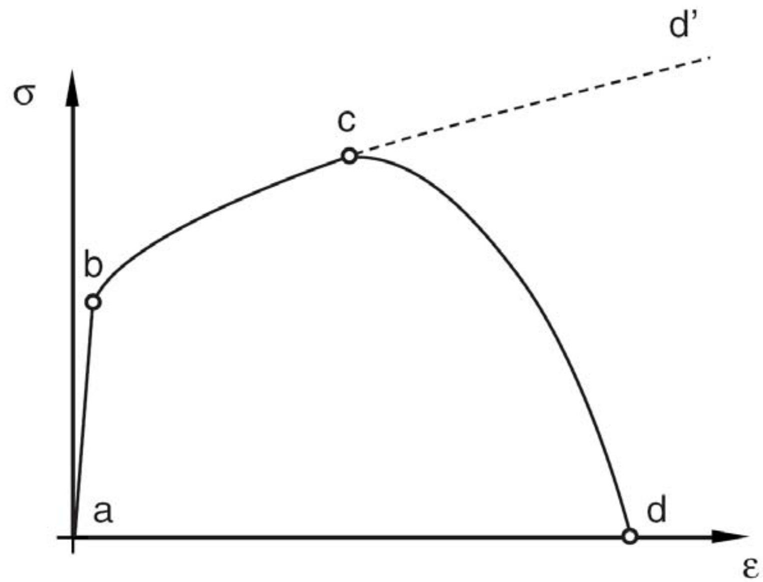
The theory of damage mechanics takes into account the process of material degradation due to the initiation, growth and coalescence of micro-cracks/voids in a ‘real-life’ material element under monotonic or cyclic or impact or thermo-mechanical loading.

A valid material failure criterion must therefore take into account the process of progressive material degradation/damage under either static or dynamic/fatigue loading.

General framework for modeling damage and failure

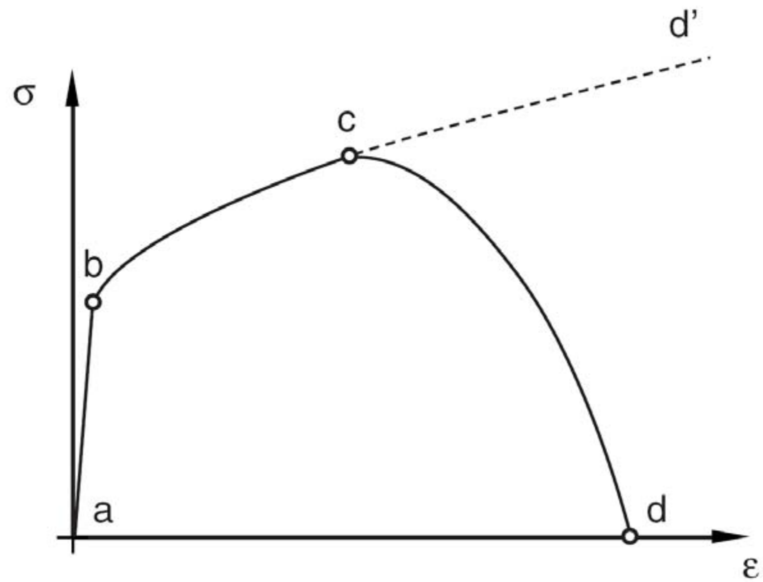
Abaqus offers a general framework for material failure modeling that allows the combination of multiple failure mechanisms acting simultaneously on the same material. Material failure refers to the complete loss of load-carrying capacity that results from progressive degradation of the material stiffness. The stiffness degradation process is modeled using damage mechanics.

Typical uniaxial stress-strain response of a metal specimen



The stress-strain response will show distinct phases. The material response is initially linear elastic, a-b , followed by plastic yielding with strain hardening, b-c . Beyond point c there is a marked reduction of load-carrying capacity until rupture, c-d . The deformation during this last phase is localized in a neck region of the specimen.

Typical uniaxial stress-strain response of a metal specimen



Point c identifies the material state at the onset of damage, which is referred to as the damage initiation criterion. Beyond this point, the stress-strain response c-d is governed by the evolution of the degradation of the stiffness in the region of strain localization. In the context of damage mechanics c-d can be viewed as the degraded response of the curve c-d' that the material would have followed in the absence of damage.

failure mechanism in ABAQUS

In Abaqus the specification of a failure mechanism consists of four distinct parts:

• the definition of the effective (or undamaged) material response (e.g., a –b – c- d'),

• a damage initiation criterion (e.g., c),

• a damage evolution law (e.g., c- d), and

• a choice of element deletion whereby elements can be removed from the calculations once the material stiffness is fully degraded (e.g., d).

failure mechanism in ABAQUS

- Mesh dependency

In continuum mechanics the constitutive model is normally expressed in terms of stress-strain relations. When the material exhibits strain-softening behavior, leading to strain localization, this formulation results in a strong mesh dependency of the finite element results in that the energy dissipated decreases upon mesh refinement. In Abaqus all of the available damage evolution models use a formulation intended to alleviate the mesh dependency. This is accomplished by introducing a characteristic length into the formulation, which in Abaqus is related to the element size, and expressing the softening part of the constitutive law as a stress-displacement relation.

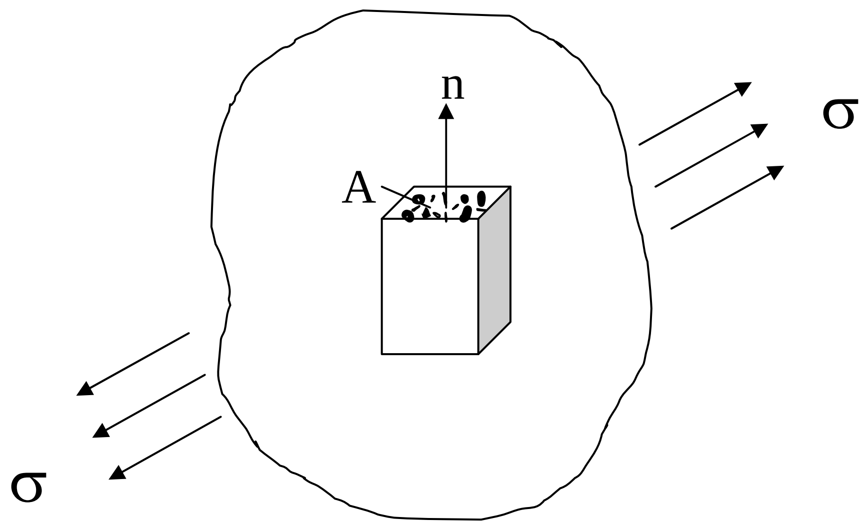
failure mechanism in ABAQUS

- Mesh dependency

In this case the energy dissipated during the damage process is specified per unit area, not per unit volume. This energy is treated as an additional material parameter, and it is used to compute the displacement at which full material damage occurs. This is consistent with the concept of critical energy release rate as a material parameter for fracture mechanics. This formulation ensures that the correct amount of energy is dissipated and greatly alleviates the mesh dependency.

Damage and failure for ductile metals

- Definition of scalar damage variable



$$\sigma = \frac{F}{A}$$

$$D = \frac{A_D}{A}$$

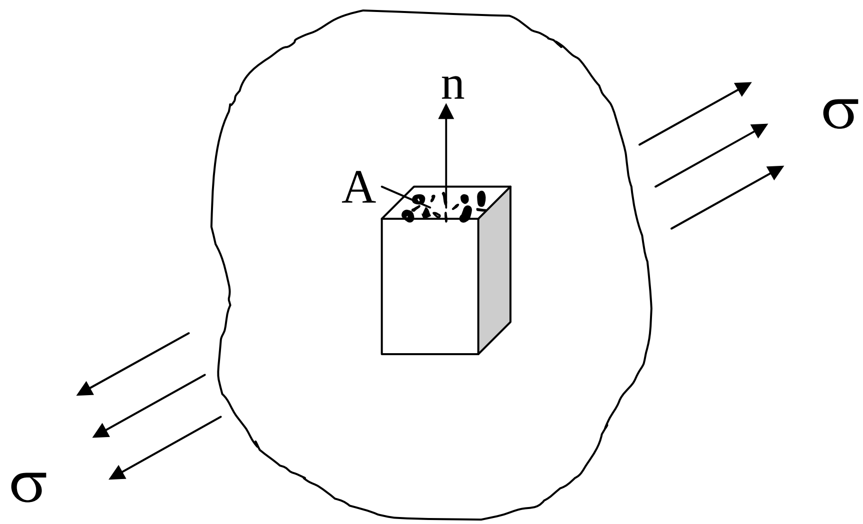
$$\bar{\sigma} = \frac{F}{A - A_D} \rightarrow \bar{\sigma} = \frac{F}{A\left(1 - \frac{A_D}{A}\right)} \rightarrow \bar{\sigma} = \frac{\sigma}{1 - D}$$

where A = original surface area (with defects);

A_D = defects surface area

Damage and failure for ductile metals

- Definition of scalar damage variable

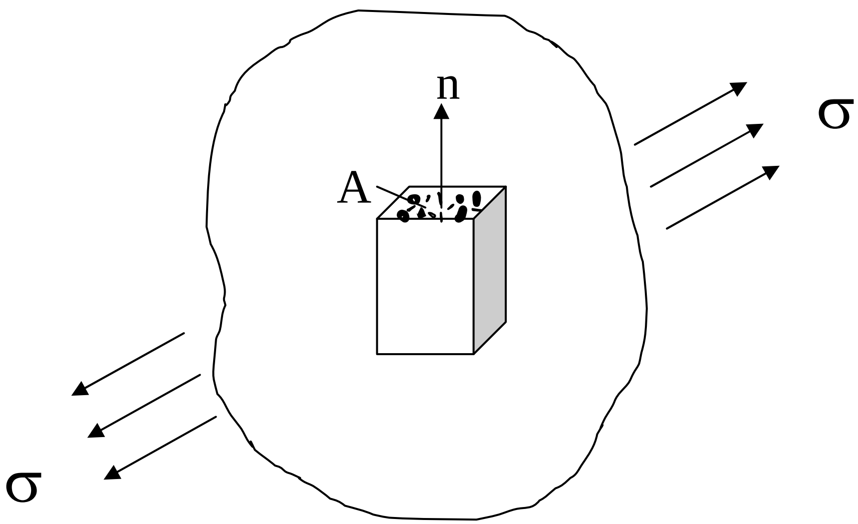


$$\sigma = (1 - D)\bar{\sigma}$$

where D is the overall damage variable and $\bar{\sigma}$ is the effective (or undamaged) stress tensor computed in the current increment. $\bar{\sigma}$ are the stresses that would exist in the material in the absence of damage. The material has lost its load-carrying capacity when D=1 .

Damage and failure for ductile metals

- Definition of scalar damage variable



$$\bar{\sigma} = \frac{\sigma}{(1-D)}$$

True stress was replaced by effective stress

$$\sigma = E_0(1-D)\varepsilon$$

Damage and failure for ductile metals

- Damage initiation criterion

Abaqus offers a variety of choices of damage initiation criteria for ductile metals, each associated with distinct types of material failure. They can be classified in the following categories:

- Damage initiation criteria for the fracture of metals, including ductile and shear criteria.
- Damage initiation criteria for the necking instability of sheet metal. These include forming limit diagrams (FLD, FLSD, and MSFLD) intended to assess the formability of sheet metal and the Marciniak-Kuczynski (M-K) criterion (available only in Abaqus/Explicit) to numerically predict necking instability in sheet metal taking into account the deformation history.

Damage and failure for ductile metals

- Damage evolution

The damage evolution law describes the rate of degradation of the material stiffness once the corresponding initiation criterion has been reached. For damage in ductile metals Abaqus/Explicit assumes that the degradation of the stiffness associated with each active failure mechanism can be modeled using a scalar damage variable, d_i .

At any given time during the analysis the stress tensor in the material is given by the scalar damage equation

$$\sigma = (1 - D)\bar{\sigma}$$

Damage and failure for ductile metals

- Damage initiation criterion

Abaqus/CAE Usage:

Property module: material editor: **Mechanical**

⟶ **Damage for Ductile Metals** ⟶ Ductile Damage

Johnson-Cook Damage

Shear Damage

FLD Damage

FLSD Damage

M-K Damage

MSFLD Damage

Damage and failure for ductile metals

- Damage evolution

Abaqus/CAE Usage:

Property module: material editor: **Mechanical**

⟶ **Damage for Ductile Metals** ⟶ **criterion: Suboptions**

⟶ **Damage Evolution**