Material parameter characterization for the Gurson model

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Contents

The Gurson [1977] model

$$F_p(\boldsymbol{\sigma}, f, \sigma_Y) = \frac{\sigma_{eq}^2}{{\sigma_Y}^2} - 1 + \underbrace{2f \cosh\left(\frac{3}{2}\frac{\sigma_m}{\sigma_Y}\right) - f^2}_{\text{Damage}} = 0$$

The Gurson [1977] model

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$$\dot{f} = (1 - f)\, tr\dot{\boldsymbol{\epsilon}}^p$$

1 new material parameter: f_0

GTN extension

The Gurson-Tvergaard-Needleman (GTN) extension:

- Nucleation [Chu and Needleman, 1980].
- (Corrected) void growth.
- Coalescence [Tvergaard and Needleman, 1984].

GTN extension

Tvergaard [1982]

$$F_p(\boldsymbol{\sigma}, f, \overline{\sigma}) = \frac{\sigma_{eq}^2}{\overline{\sigma}^2} - 1 + 2q_1 f \cosh\left(-\frac{3}{2} q_2 \frac{\sigma_m}{\overline{\sigma}}\right) - q_3 f^2 = 0$$

GTN extension

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$$F_p(\boldsymbol{\sigma}, f, \overline{\sigma}) = \frac{\sigma_{eq}^2}{\overline{\sigma}^2} - 1 + 2\boxed{q_1} f \cosh\left(-\frac{3\boxed{q_2}\sigma_m}{2\overline{\sigma}}\right) - \boxed{q_3} f^2 = 0$$

2 new material parameters: q_1*,* q_2 *(*$q_3 = {q_1}^2$*)*

Nucleation
Chu and Needleman [1980]

$$\dot{f} = \dot{f}_g + \dot{f}_n + \dot{f}_s$$

$$\dot{f}_n = \underbrace{\mathcal{A}\dot{\epsilon}^P_{eq}}_{\text{Strain}} + \underbrace{\mathcal{B}\left(\dot{\sigma}_{eq} + c\dot{\sigma}_M\right)}_{\text{Stress}}$$

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$$\mathcal{A}(\epsilon_{eq}) = \frac{1}{\sqrt{2\pi}}\frac{f_N}{S_N}\exp\left[-\frac{1}{2}\left(\frac{\epsilon_{eq} - \epsilon_N}{S_N}\right)^2\right]$$

$$\mathcal{B}(\boldsymbol{\sigma}) = 0$$

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$$\mathcal{B}(\boldsymbol{\sigma}) = 0$$

3 new parameters: f_N, ϵ_N, S_N

Coalescence

Tvergaard and Needleman [1984]

$$f^* = \begin{cases} f & \text{if } f < f_{cr} \\ f_{cr} + \dfrac{f_u - f_{cr}}{f_F - f_{cr}}(f - f_{cr}) & \text{if } f > f_{cr} \end{cases}$$

Coalescence

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2 new parameters: f_{cr}, f_F $\left(f_u = \dfrac{1}{q_1}\right)$

Shear extension

Xue [2008]; Nahshon and Hutchinson [2008]

$$\dot{f} = \dot{f}_g + \dot{f}_n + \dot{f}_s$$

$$\dot{f}_s = k_\omega f \omega(\boldsymbol{s}) \frac{\boldsymbol{s}\dot{\epsilon}^P}{\sigma_{eq}}$$

Shear extension

Xue [2008]; Nahshon and Hutchinson [2008]

$$\dot{f} = \dot{f}_g + \dot{f}_n + \dot{f}_s$$

$$\dot{f}_s = \boxed{k_\omega} f \omega(\boldsymbol{s}) \frac{\boldsymbol{s}\dot{\epsilon}^P}{\sigma_{eq}}$$

1 new parameter: k_ω

Resuming. . .

9 material parameters:

- f_0
- q_1, q_2
- Nucleation: f_N, ϵ_N, S_N
- Coalescence: f_{cr}, f_F
- Shear: k_ω

GTN characterization

Approaches

- Microscopic measurements.
- Macroscopic measurements.
- Hybrid experimental-numerical.

GTN characterization

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- Microscopic measurements.
- Macroscopic measurements.
- Hybrid experimental-numerical.

Criteria

- Parameter scale.
- Nature of the parameter (stress state based, fitting, etc.).

Microscopic approach

- Image analysis, 3D tomography, *in-situ* neutron diffraction,. . .
- Use whenever it is possible.

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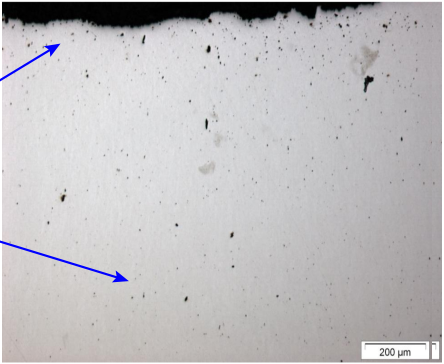
We can identify 4(5) parameters:

$$f_0,\ f_N,\ f_{cr},\ f_F,\ (S_N)$$

Tensile test DC01 steel

f_F measurement:

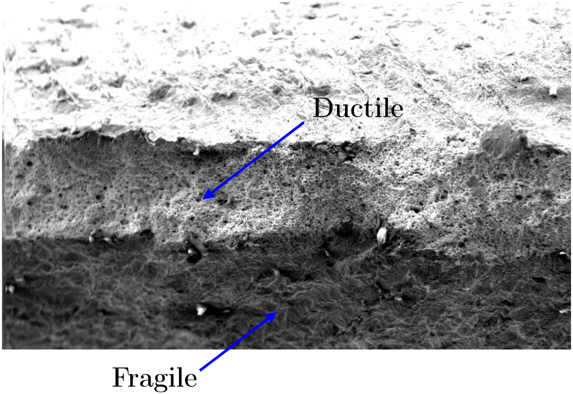


$f = 0.4 - 0.5\%$

$f = 0.04 - 0.07\%$

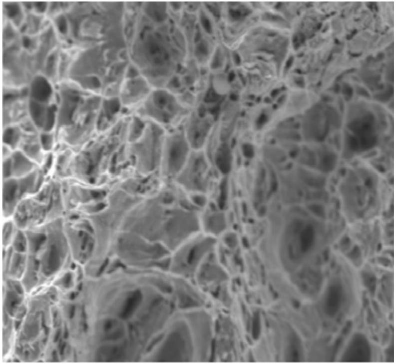
Tensile test DC01 steel

- Other variables: void spacing, size, distribution S_N, etc.
- Qualitative measurements:

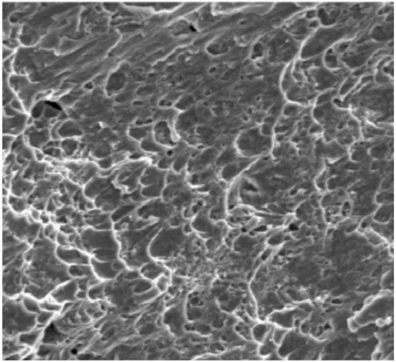


Ductile vs. fragile

Barsoum and Faleskog [2007]



Cavity controlled (Dimples)
$T = 1.10$



Shear controlled
$T = 0.47$

Macroscopic approach

- Different notch radius for different triaxiality.
- DIC measurements.

Measurements

- Load-displacement curve.
- Displacement at the onset of fracture and at fracture.
- (Sheet) thickness.
- DIC: crack appearance.
- DIC: strain path to fracture.

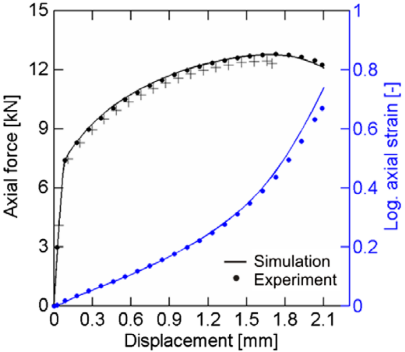
We can identify 1(3) parameters:

$$\epsilon_N \ (q_1,\, q_2)$$

Onset of fracture

Dunand and Mohr [2010]

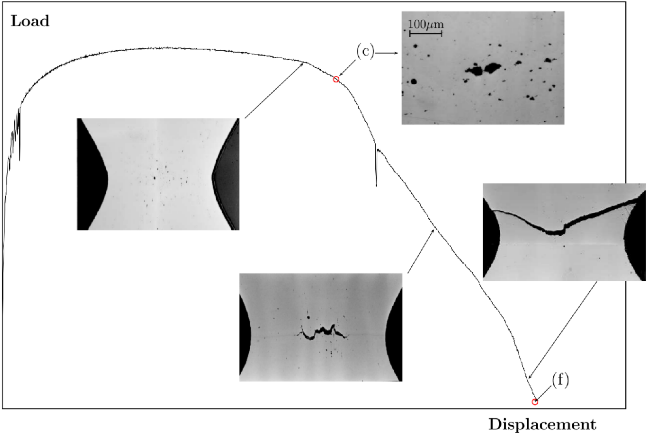
Location of the onset of fracture:



Cup-to-cone fracture

Benzerga and Leblond [2010]

Macro-micro approach:



Hybrid numerical-experimental

Finite element simulations coupled with experiments.

Inverse modeling

- Deterministic (OPTIM)
- Stochastic (AI_Lagamine)

Simple methodology

Li et al. [2011]

- Al-alloy 6061 T6
- GTN model (without shear).

1. f_0 =0.02 from image analysis.
2. q_1 =1.25 and q_2 =1.0 fixed.
3. ϵ_N =0.3, S_N =0.01, f_N =0.02 fixed.
4. f_c =0.045 and f_F =0.0475 obtained through iterations.

Numerical methodology

Xue et al. [2010]

- DH36 steel
- Gurson+coalescence+shear
- No microscopic measurements are available.

Numerical methodology

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1. n from a single tensile test.
2. f_0 and D (element size) from the load-displacement cracked specimen.
3. No information about $f_F =$0.25, $f_{cr} =$0.15.
4. k_ω from a shear-off test.

Hybrid methodology

Dunand and Mohr [2010, 2011]

- TRIP780 steel sheets.
- GTN+shear.
- Multiaxial tests and error assesment.
- stress and strain from hybrid experimental-numerical.
- No inverse modeling.

Hybrid methodology

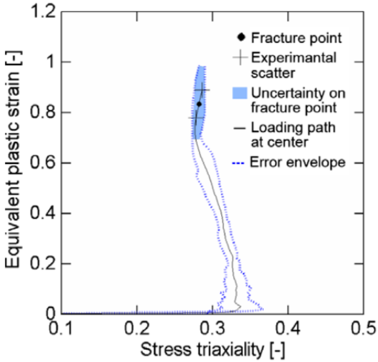
Dunand and Mohr [2010, 2011]

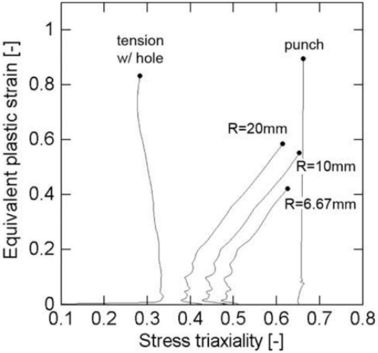
- TRIP780 steel sheets.
- GTN+shear.
- Multiaxial tests and error assesment.
- stress and strain from hybrid experimental-numerical.
- No inverse modeling.

1. $f_0 = 6 \times 10^{-5}$ from image analysis.
2. Nucleation parameters fitted from *tensile* specimen.
3. q_1 and q_2 from a punch test.
4. Coalescence parameters from the punch test.
5. k_ω from butterfly test (shear).

Hybrid methodology

Dunand and Mohr [2010, 2011]





To keep in mind…

- Bad plasticity modeling ⇒ bad damage modeling (coupled criteria)
- Fracture is very sensible to loading paths: diverse test are needed.
- The sensibility of the load-displacement curve to the parameters should be evaluated.
- Post-necking behaviour seems to be important.

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