Effect of strain rate on the forming behaviour of sheet metals

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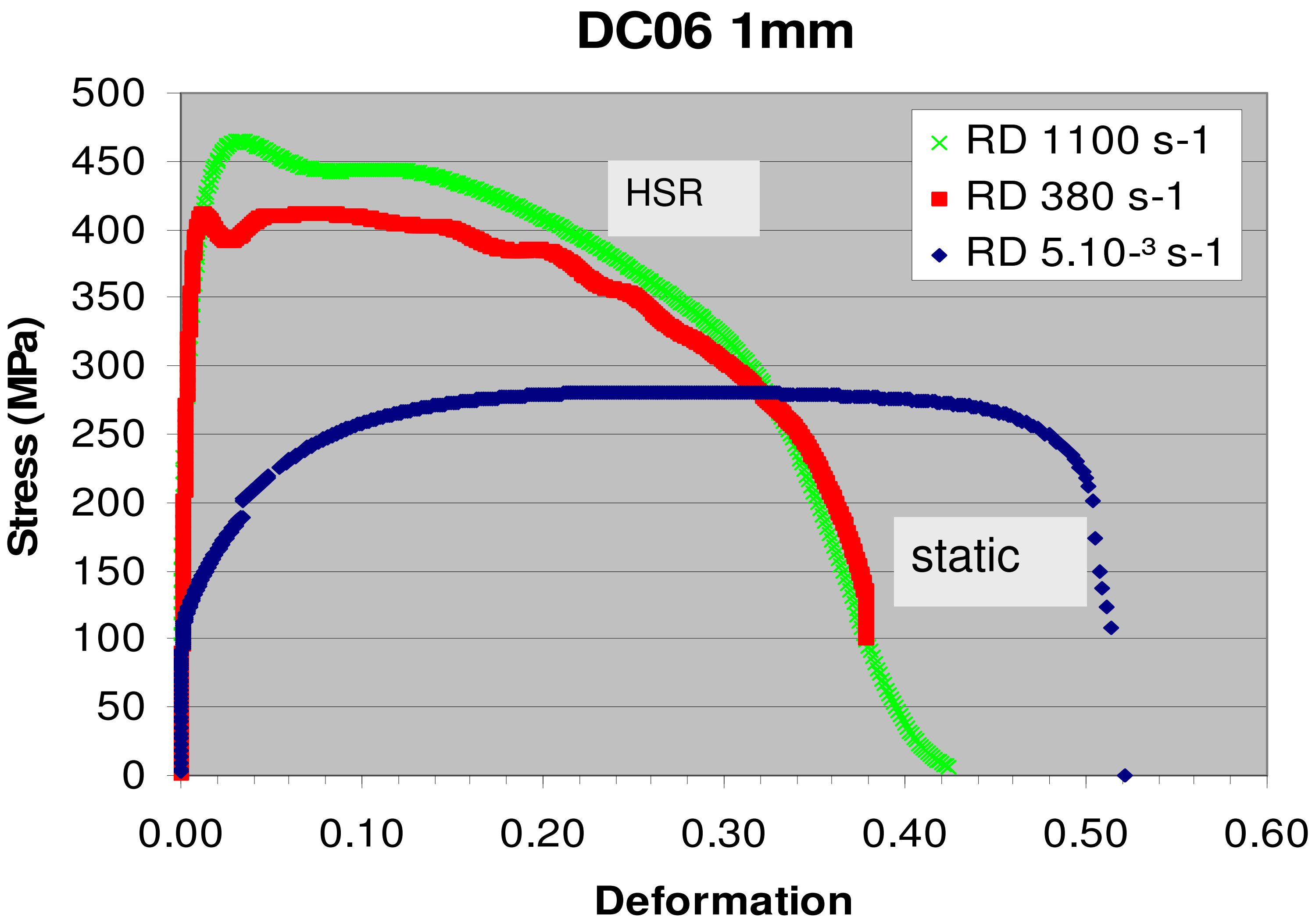
DC06 1mm
Stress (MPa)
Deformation
0
50
100
150
200
250
300
350
400
450
500
0.00
0.10
0.20
0.30
0.40
0.50
0.60
RD 1100 s-1
RD 380 s-1
RD 5.10-3 s-1
HSR
static

Processes and materials of interest

Forming processes

- Electromagnetic pulse forming, hydroforming
  - Strain rates upto 3500/s
- Deepdrawing, roll forming, bending
  - Locally strain rates upto 100/s

Materials

- DC04 (EN 10027-1)
  - unalloyed deep-drawing steel
  - used for body components in cars
- CMnAl TRIP
  - laboratory made
  - multiphase
  - austenite transforms to martensite during plastic straining

Overview

- Experiments
- Modelling of high strain rate behaviour
- Calculation of high strain rate FLD
- Conclusions

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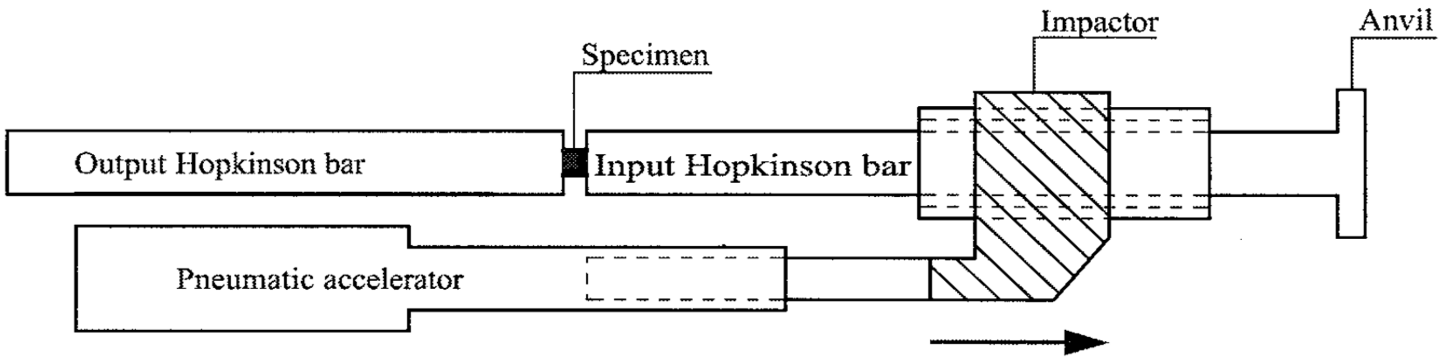
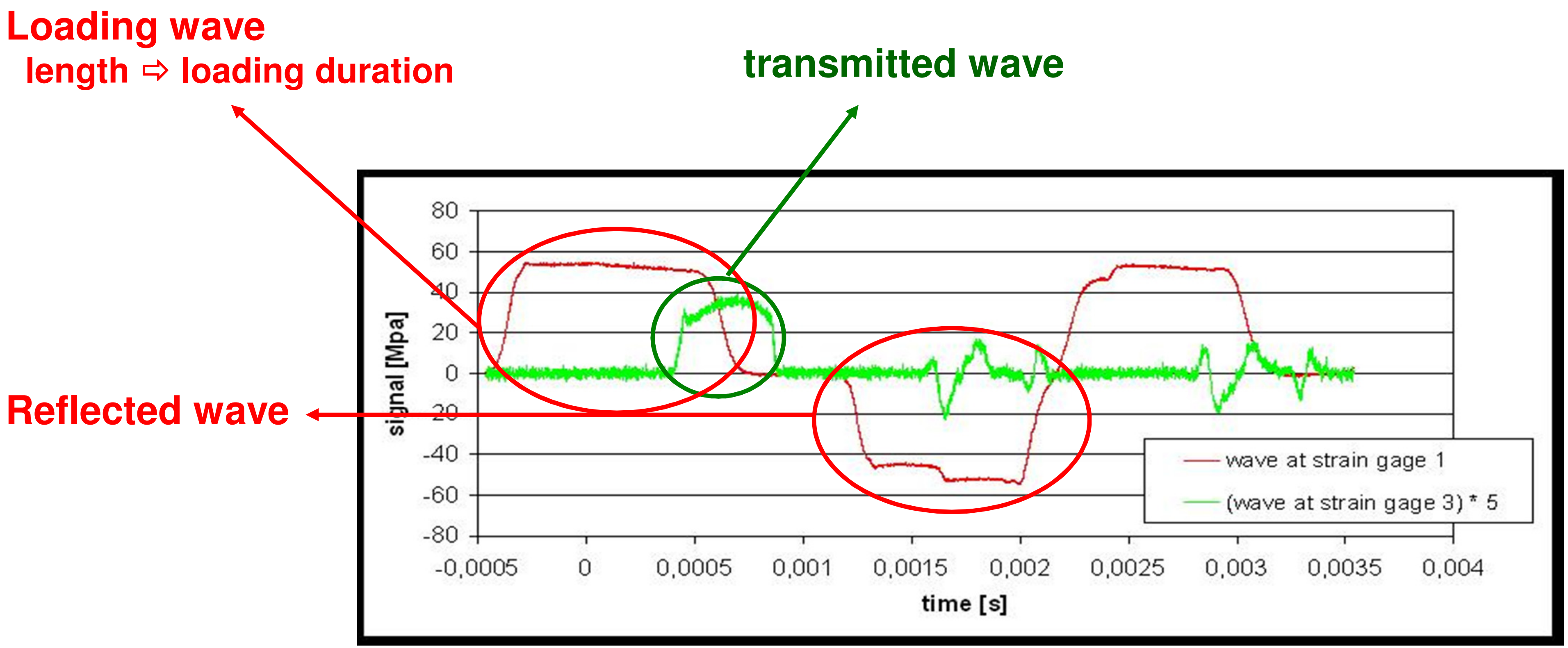
Split Hopkinson tensile bar experiments

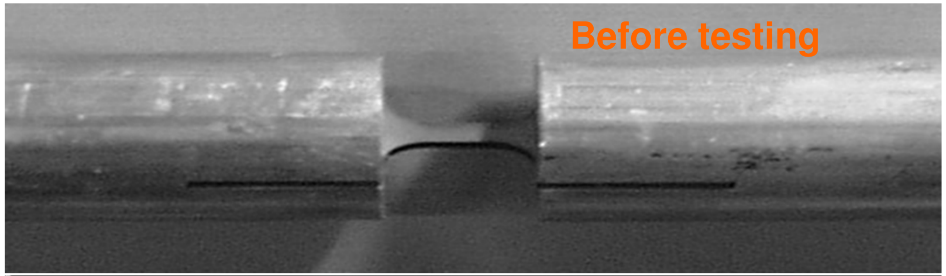


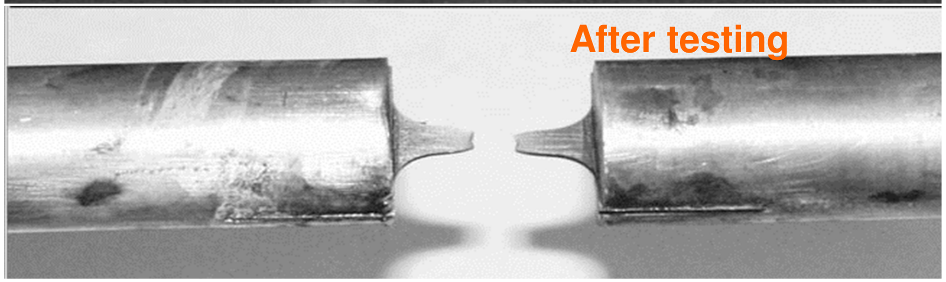


Split Hopkinson tensile bar experiments

Setup at Ghent University

- Uniaxial ***tensile*** load
- Adjustable ***strain rate*** up to ~2000 s^{-1}
- ***Loading time*** up to 1.2 ms
- Specimen ***glued*** between bars





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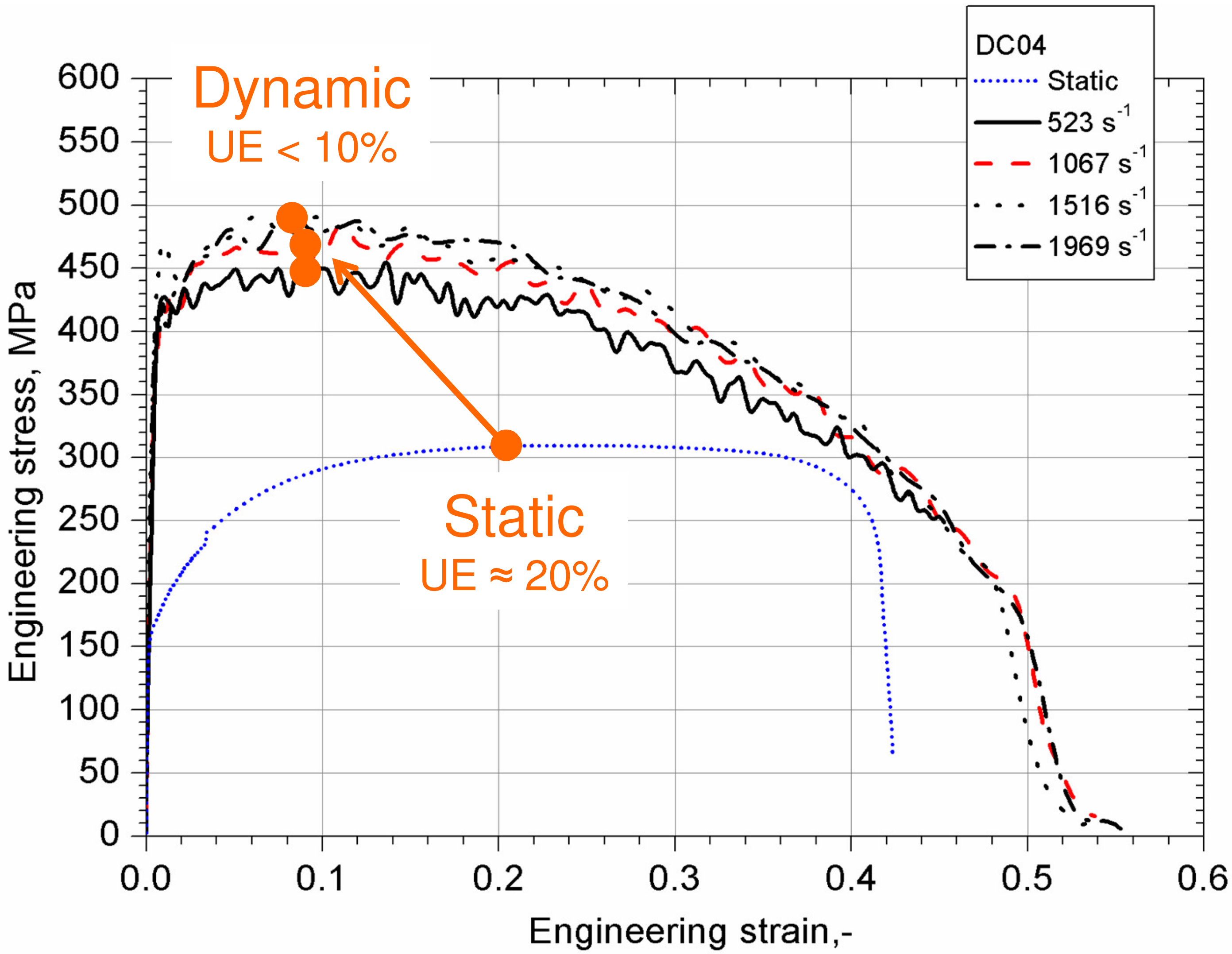
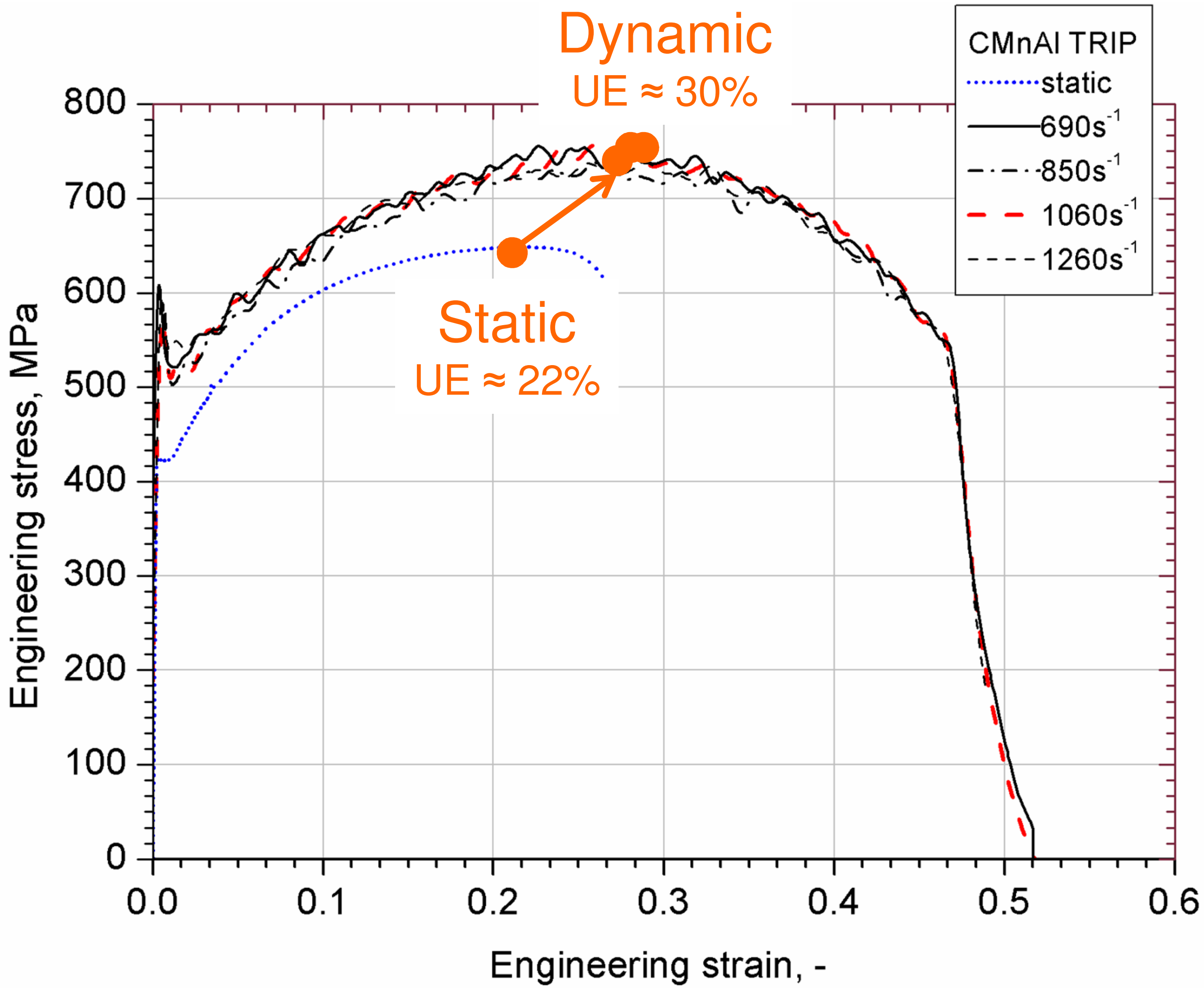
Test results



Test results



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Phenomenological modeling

Johnson-Cook

- Strain rate dependent hardening
- Temperature dependent softening

$$\sigma = \left(\mathrm{A} + \mathrm{B}\varepsilon^{\mathrm{n}} \right)\left(1 + C \ln \frac{\dot{\varepsilon}}{\dot{\varepsilon}_0} \right)\left(1 - \left[\frac{T - T_{room}}{T_{melt} - T_{room}} \right]^m \right)$$

adiabatic heating

$$\Delta T = \frac{\beta}{\rho c} \int \sigma d\, \varepsilon_p$$

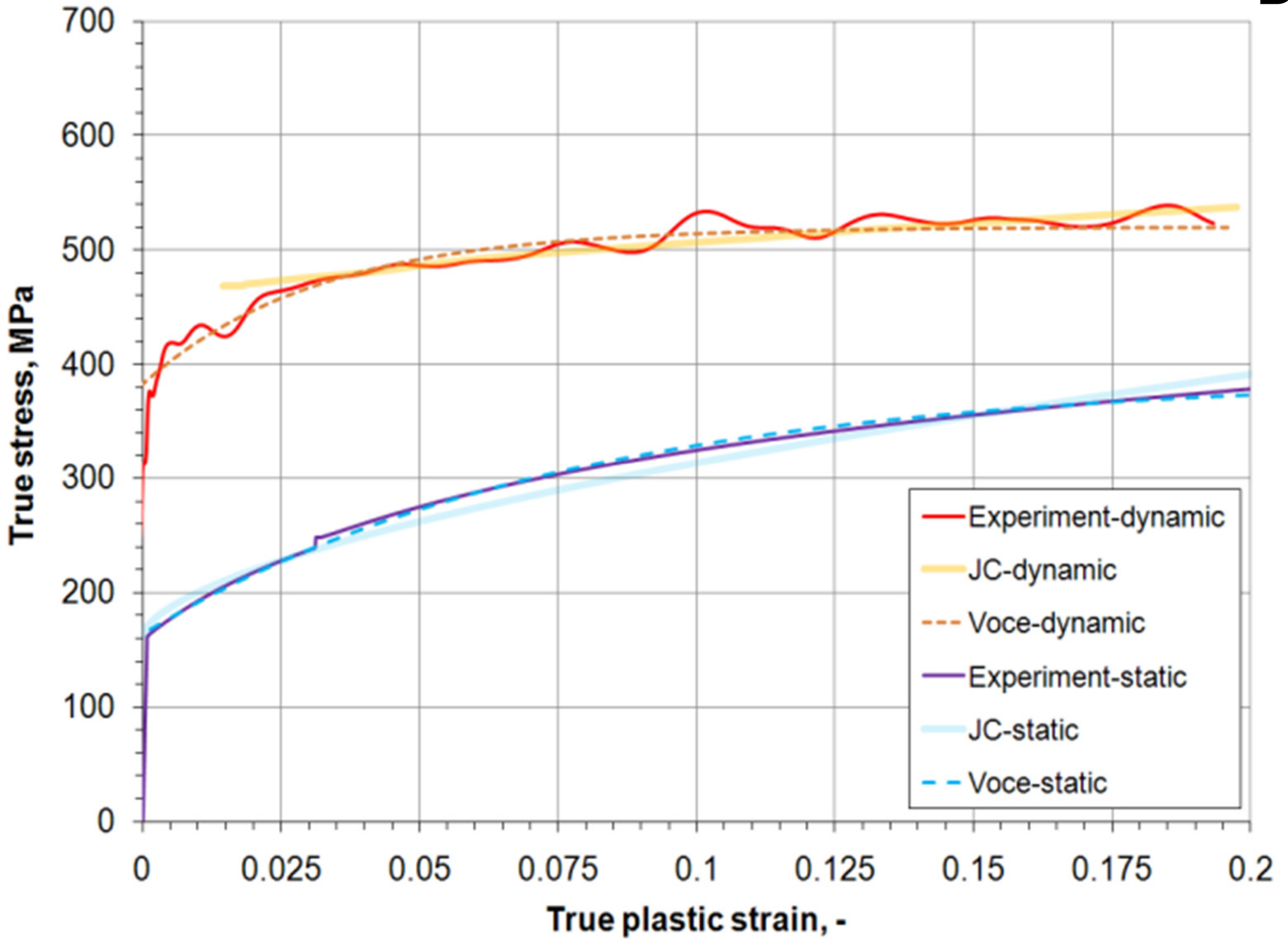
Voce

- *Strain rate dependence* and *adiabatic conditions* accounted for by the use of strain rate dependent parameters

$$\sigma = \sigma_0 + K(1 - e^{-n\varepsilon_p})$$

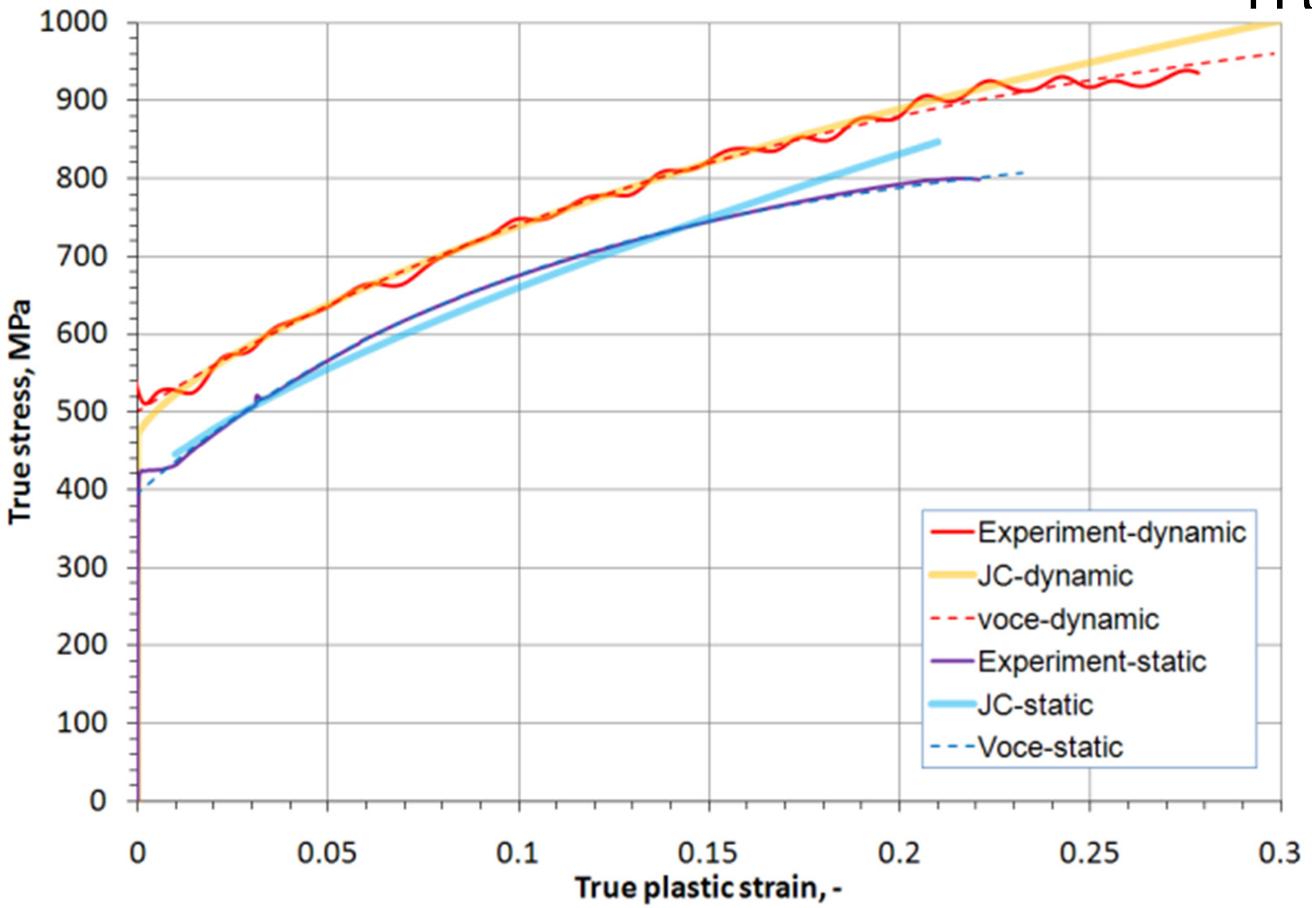
Modelling

DC04



Modelling

TRIP



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Calculation of high strain rate FLD

- Marciniak-Kuczynski model

  initial imperfection in sheet metal modelled by band of smaller thickness

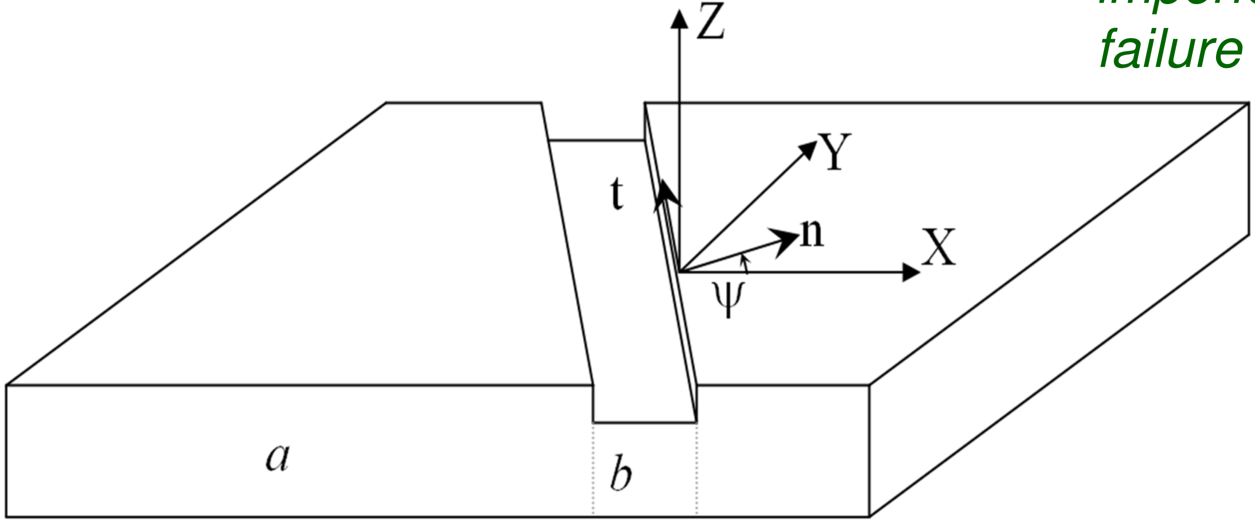
  during *biaxial straining* imperfection zone deforms more than uniform zone

  when *strain localizes*, difference increases drastically

  failure of sheet

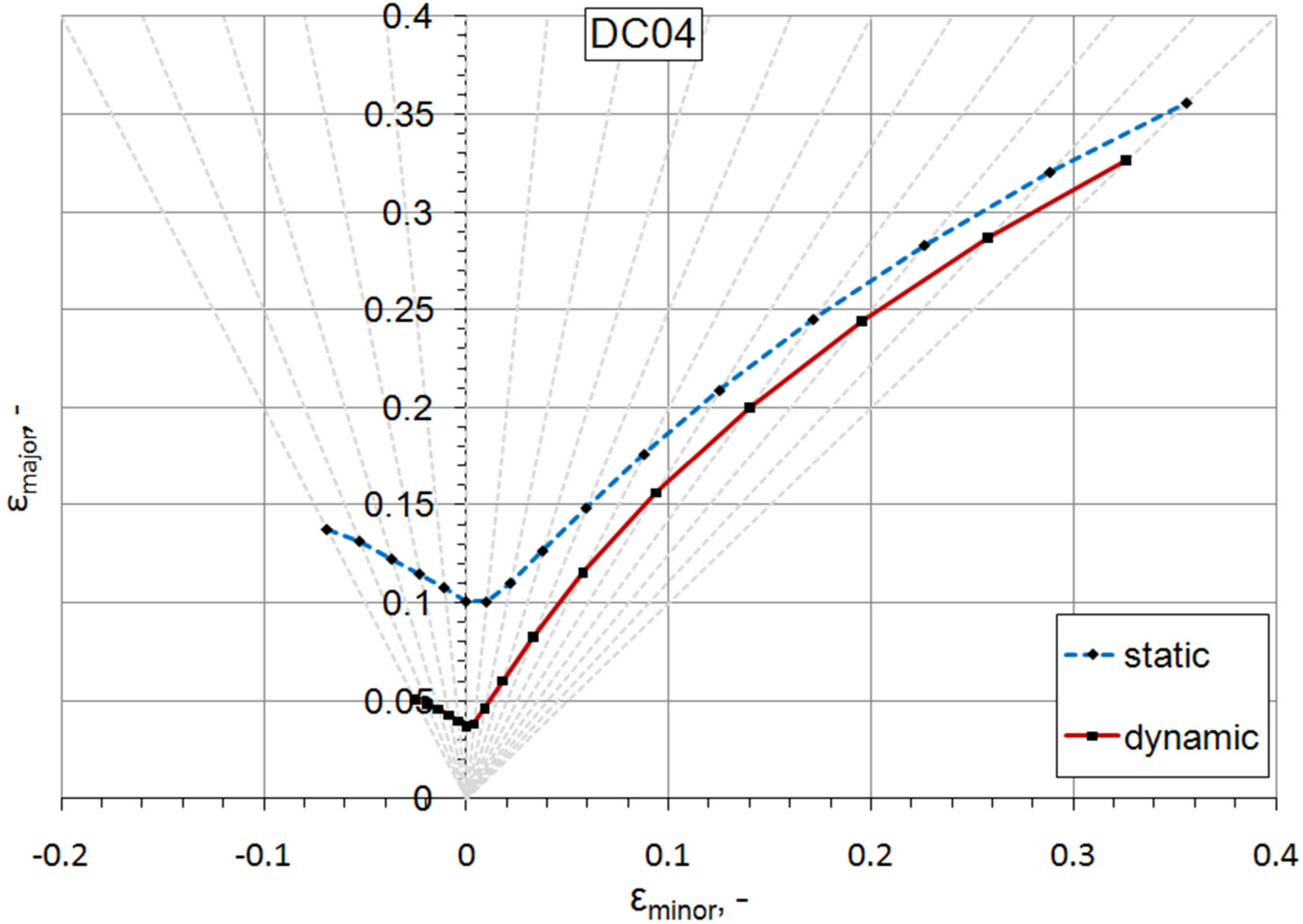
Calculation of high strain rate FLD

orientation of band → ψ
imperfection → $f_0=t_{b0}/t_{a0}=0.99$
failure if ratio of strain in b to a=4

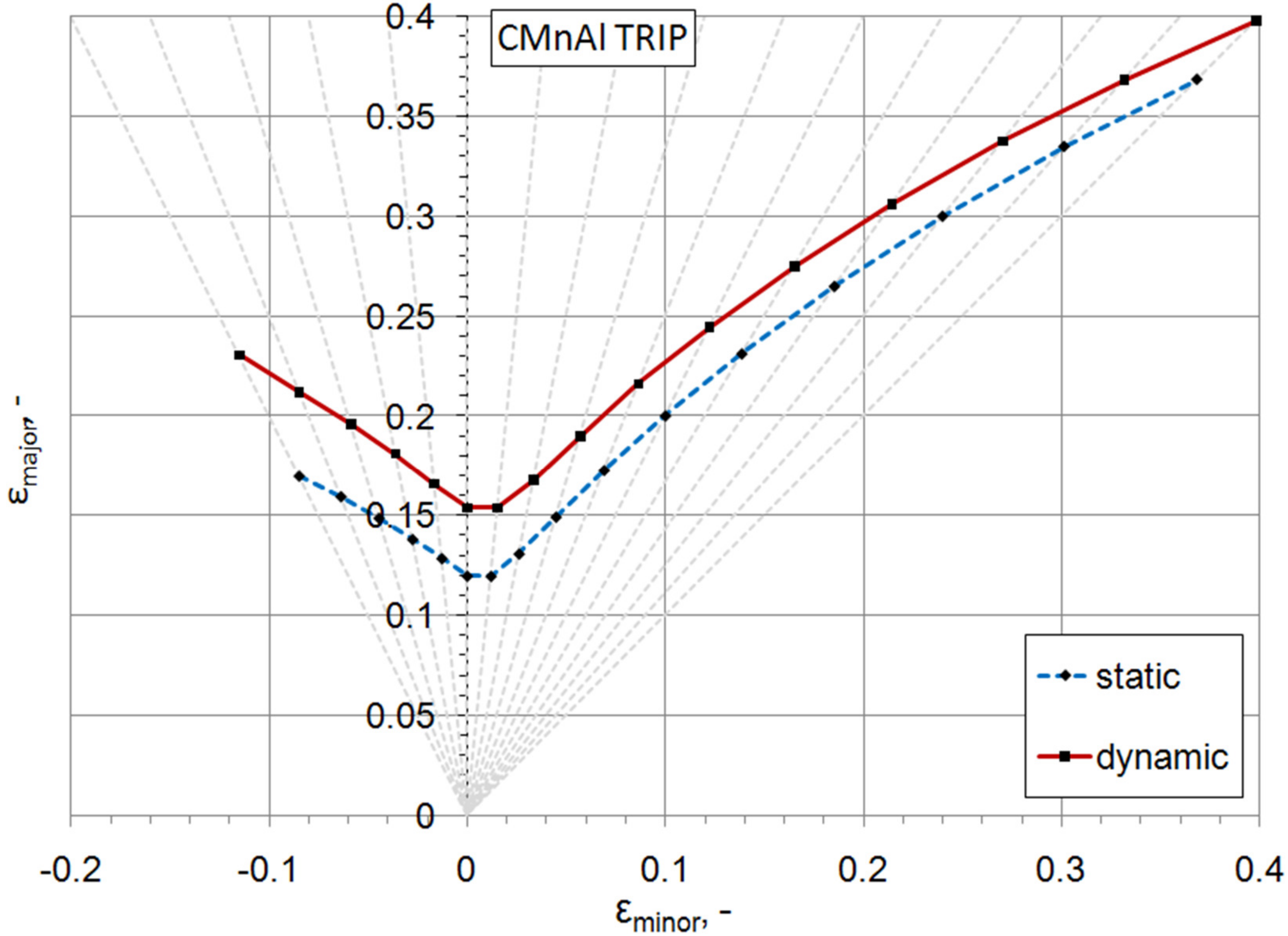


For a certain predefined *biaxial strain state*
critical strain calculated for all ψ angles
Lowest strain value is ***THE critical strain***

Calculation of high strain rate FLD



Calculation of high strain rate FLD



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Conclusions

- *Influence of strain rate on forming properties* of DC04 and a CMnAl TRIP steel is studied
    - *High strain rate tensile experiments* are carried out
    - *Johnson-Cook and Voce model* parameters determined
    - Experimental results are used to calculate *FLDs*
        - based on Marciniak-Kuczynski model
- *Forming limit diagrams* show a non-negligible effect of the strain rate
    - DC04 *FLD shifts downwards* with increasing strain rate
    - TRIP *FLD enhances* considerably if the strain rate is increased

Remarks

- *Anisotropy* not taken into account in FLDs

  Limitation due to implementation, not inherent to M-K model

  – now Hill implemented

- *Post-necking* behaviour not taken into account

  Better results obtained with shear tests instead of tensile tests

Questions ??

More information:

Verleysen, P; Peirs, J; Van Slycken, J; Faes, K and Duchene, L (2011): Effect of strain rate on the forming behaviour of sheet metals. Journal of materials processing technology nr. 8, Vol. 211, 1457-1464

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