Calibration of criteria in GISSMO for metal failure prediction

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Outline

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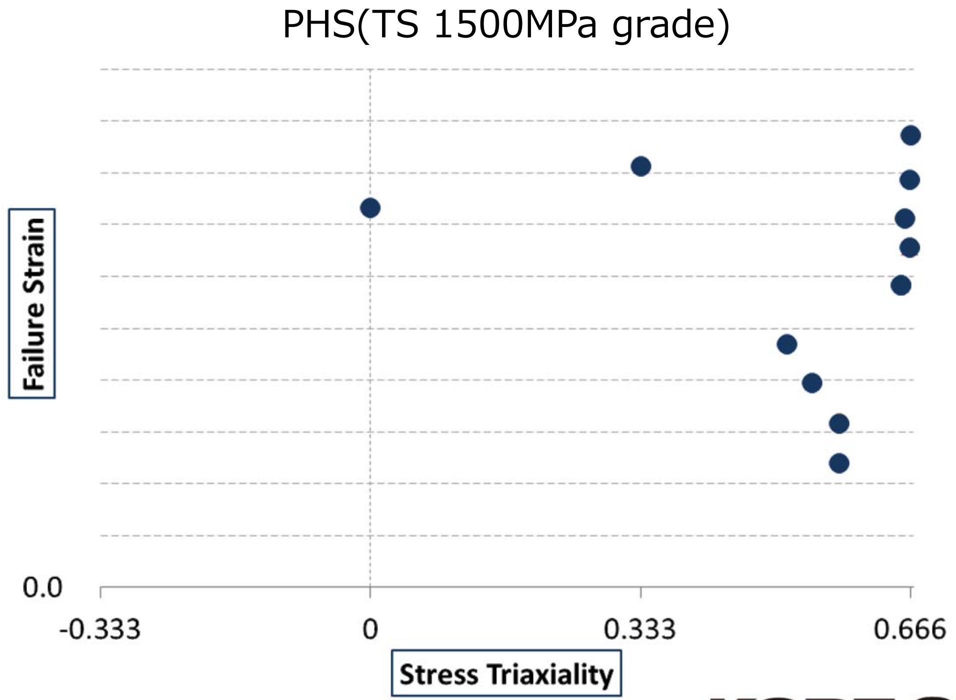
- Experiments
- Material properties
- FE modelling
- GISSMO: failure model in LS-DYNA
  - phenomenological failure model
  - Definition of failure strain
  - Material instability
- Numerical validation
- Conclusion

Background

- Failure strain in deformed metals strongly depends on hydrostatic pressure.
  - Stress Triaxiality is the most important parameter for prediction fracture in metal sheets.
  - In general cases, considering failure strain in wide range of stress triaxiality is important in order to predict material failure accurately.



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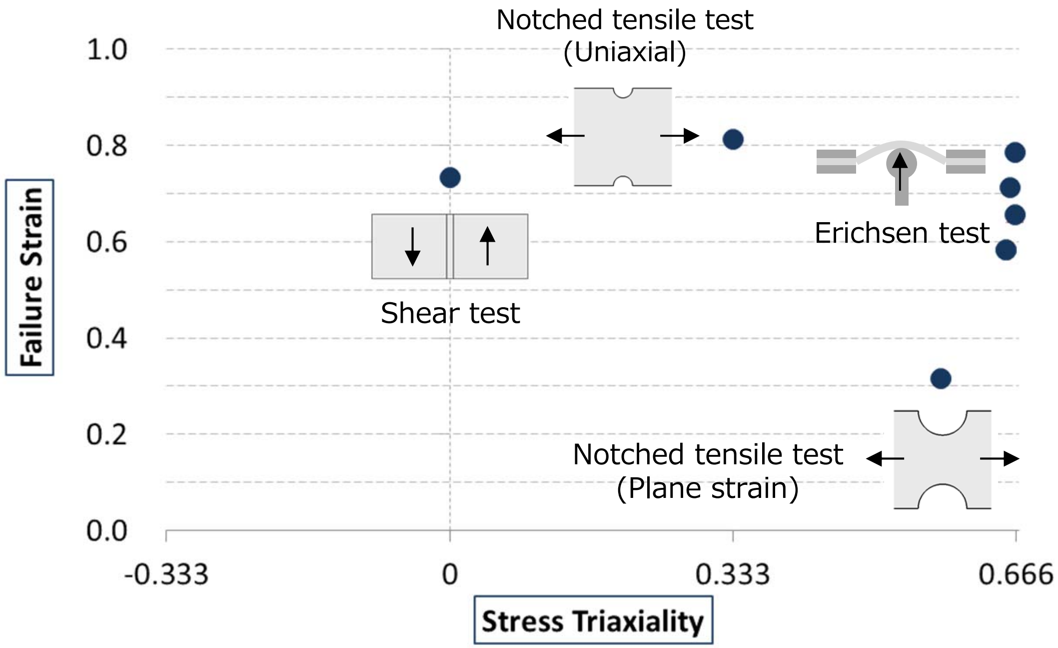
Experiments

- 5 types of test were conducted using PHS(TS1500MPa grade) to identify failure strain in various stress states.
  - JIS(Japanese Industry Standard) No.5 tensile test
    - ✓ Used to calibrate material properties
  - Notched tensile test(uniaxial and plane strain)
  - Shear test
  - Erichsen tests

JIS No.5 Tensile test



measured failure strain in each experiment

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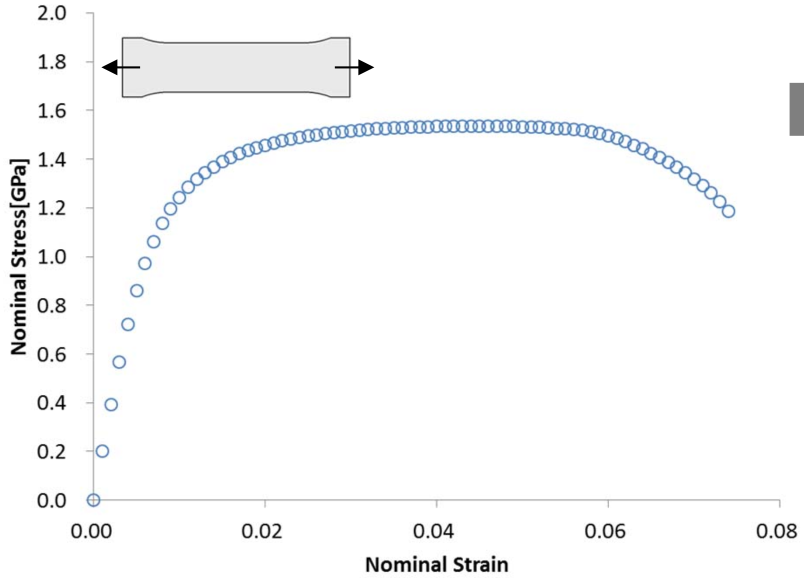
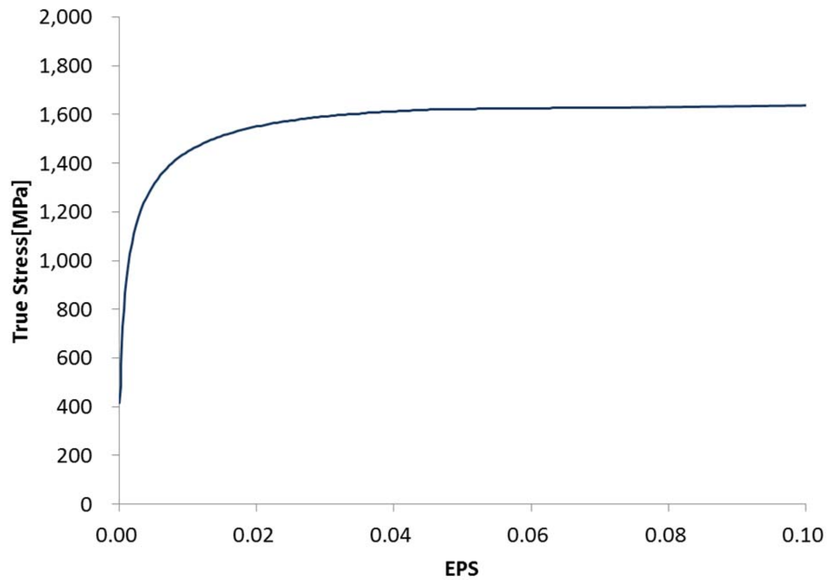
Material properties

- Identified the material property with JIS No.5 tensile test.
  - Post necking hardening would be calibrated in order to reproduce force-displacement curve in experiment by damage.

Material Properties(PHS)

Young Modulus (MPa)	Poisson Ratio (-)
2.07×10^5	0.3





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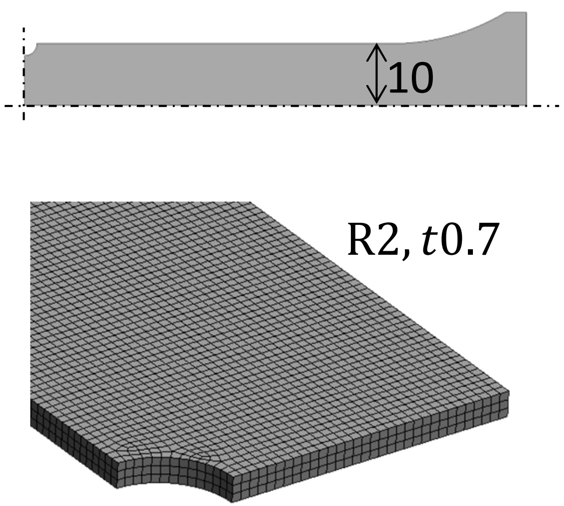
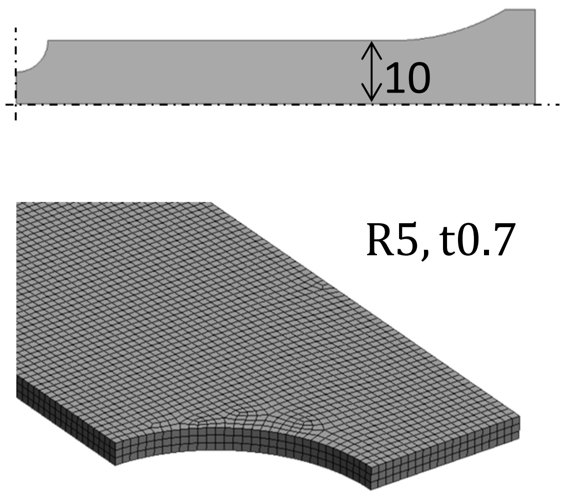
FE Model

- 0.25mm solid element with fully integrated S/R solid(elform=-1)
  - Notched tensile(plane strain, uniaxial) : 1/8 symmetrical model

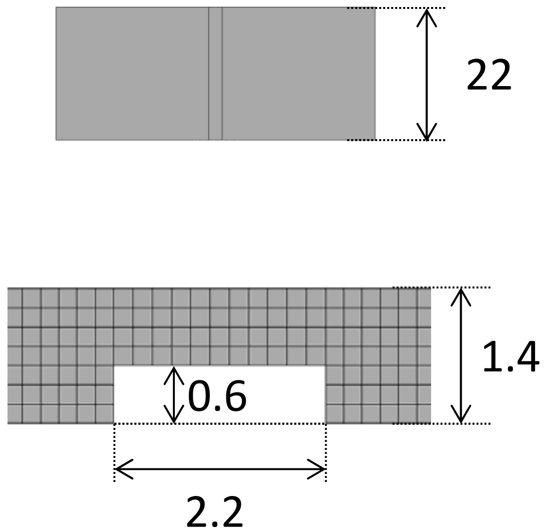
Notched tensile test
(Plane strain)



Notched tensile test
(Uniaxial)



Shear test



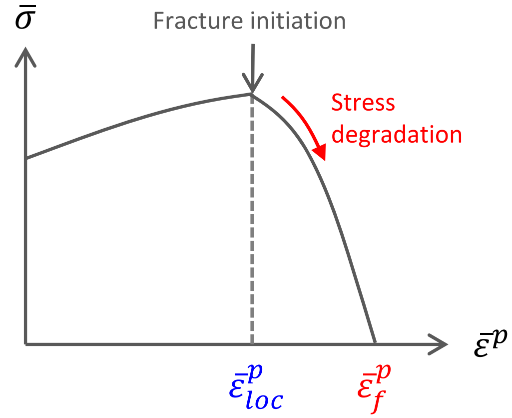
GISSMO: failure model in LS-DYNA

- User needs to define critical/failure strain as function of stress triaxiality.
  - GISSMO also accepts to define failure strain as table of triaxiality and lode angle.

◆ Damage accumulation

$$\Delta D = \frac{\mathrm{DMGEXP}}{\bar{\varepsilon}_f^p} D^{\left(1-\frac{1}{DMGEXP}\right)} \Delta\bar{\varepsilon}^p$$

- $\bar{\varepsilon}_f^p$:failure strain(stress triaxiality and lode parameter dependent.)
- $DMGEXP$: Exponent for nonlinear damage accumulation.
- D=1 induces element deletion.

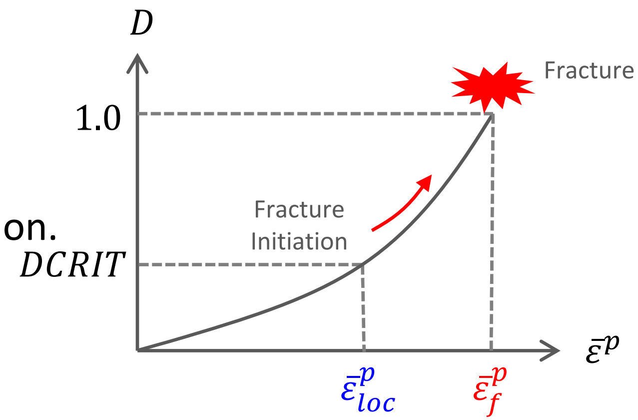


◆ Stress degradation criterion

$$\Delta F = \frac{\mathrm{DMGEXP}}{\bar{\varepsilon}_{loc}^p} F^{\left(1-\frac{1}{DMGEXP}\right)} \Delta\bar{\varepsilon}^p$$

- $\bar{\varepsilon}_{loc}^p$:critical strain(stress triaxiality dependent.)
- $DMGEXP$: Exponent for nonlinear damage accumulation.
- F=1 induces stress softening.

$$\bar{\sigma} = \tilde{\sigma}\left(1-\left(\frac{D-DCRIT}{1-DCRIT}\right)^{FADEXP}\right)$$



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Phenomenological failure model

- Material failure model proposed by Hooputra et al. [1] was used to predict plastic strain – stress triaxiality relation.
  - Ductile fracture and shear fracture

$$\bar{\varepsilon}_f^{ductile} = d_0 e^{-3c\eta} + d_1 e^{3c\eta}$$

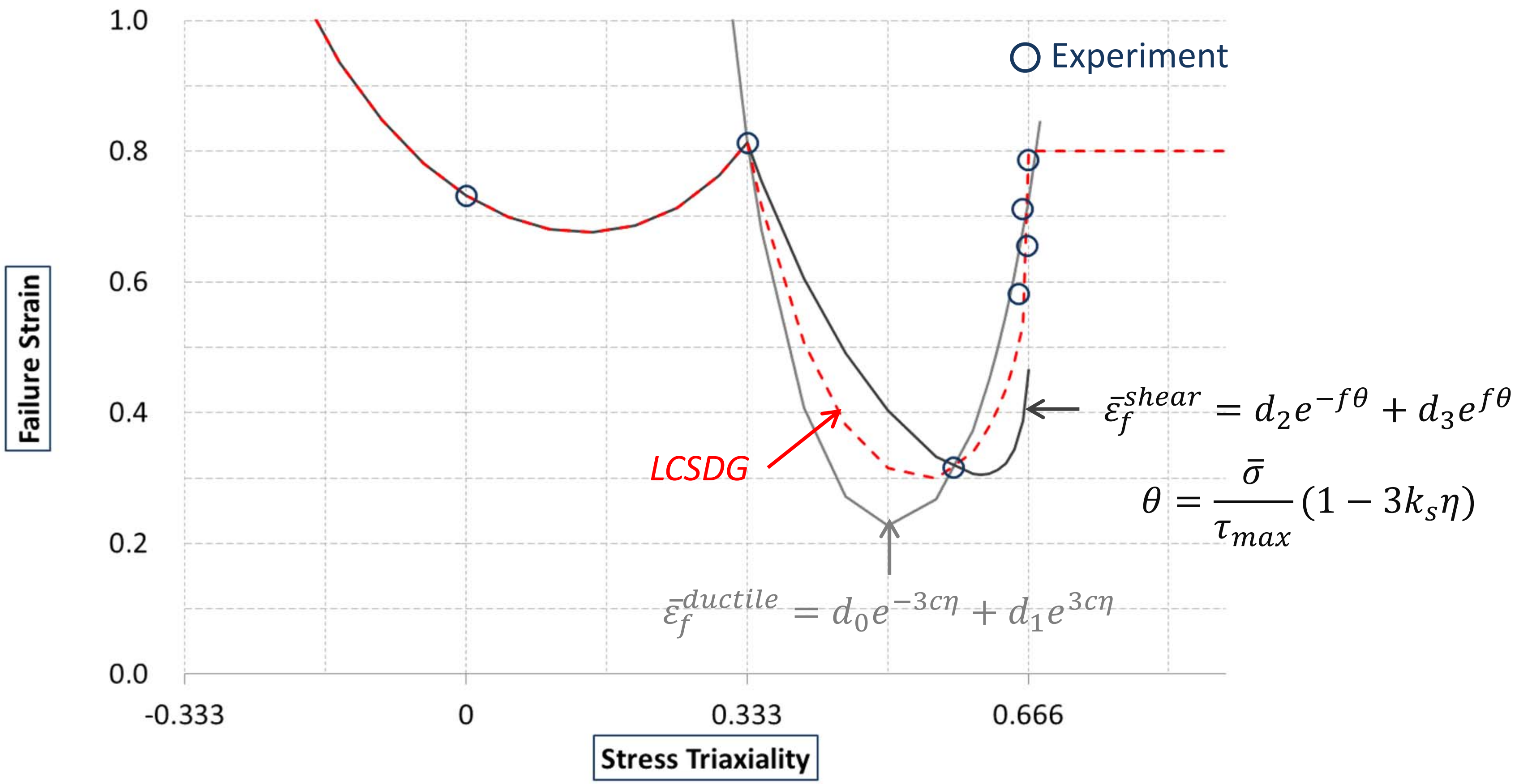
$$\bar{\varepsilon}_f^{shear} = d_2 e^{-f\theta} + d_3 e^{f\theta} \qquad \theta = \frac{\bar{\sigma}}{\tau_{max}}(1 - 3k_s\eta)$$

$d_o, d_1, c, d_2, d_3, f, k_s$: *material constant*
$\bar{\sigma}$: *euqivalent stress*, τ_{max}: *maximum shear stress*, η: *stress triaxiality*

[1] Hooputra, H., et al. "A comprehensive failure model for crashworthiness simulation of aluminium extrusions." International Journal of Crashworthiness 9.5 (2004): 449-464.

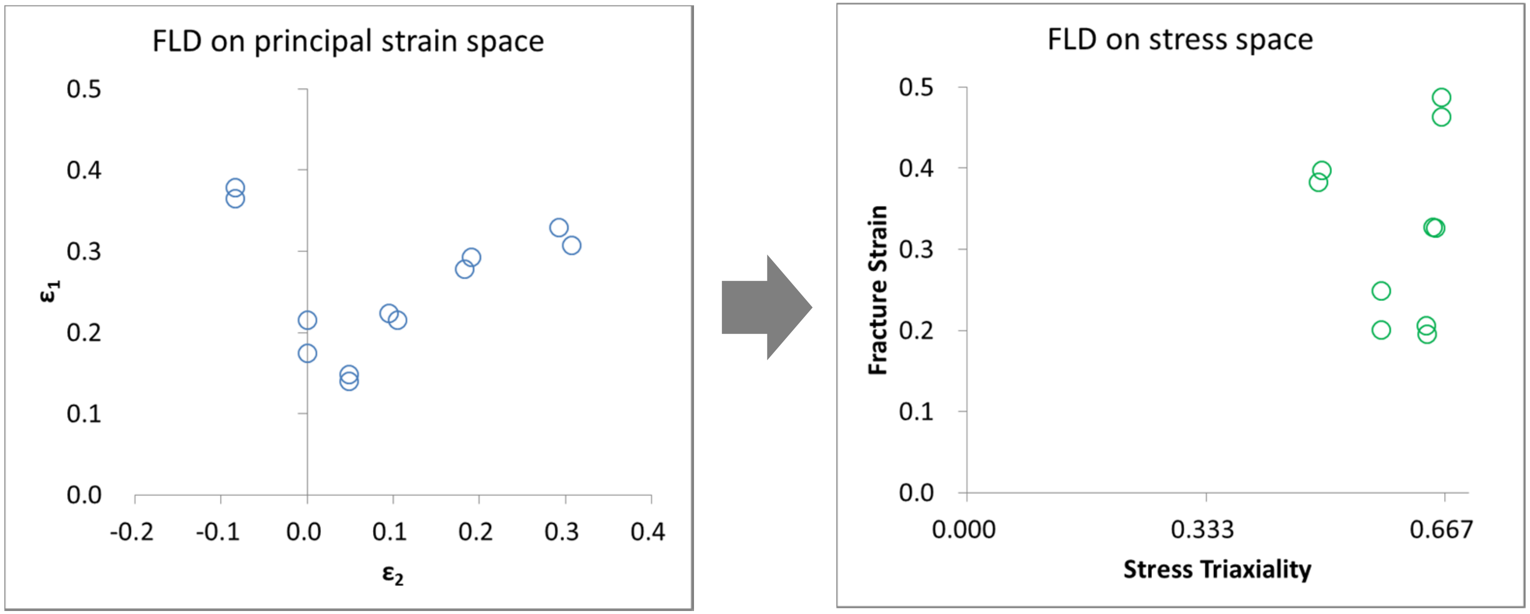
Definition of failure strain

- Fitting failure equation with nonlinear least-square method.
  - Referring to the two curves, decided the failure curve $\bar{\varepsilon}_f^p(\eta)$ which is input as LCSDG in *MAT_ADD_EROSION.



Material Instability

- Critical strain $\bar{\varepsilon}^{p}_{loc}$ depending on stress triaxiality
  - FLD(Forming Limit Diagram) could be helpful to define stress triaxiality dependent critical strain.



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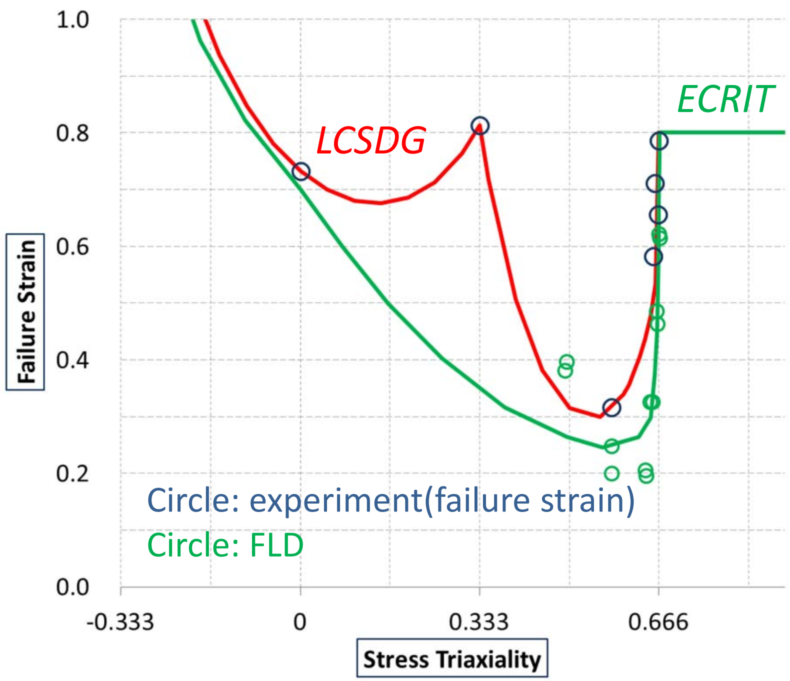
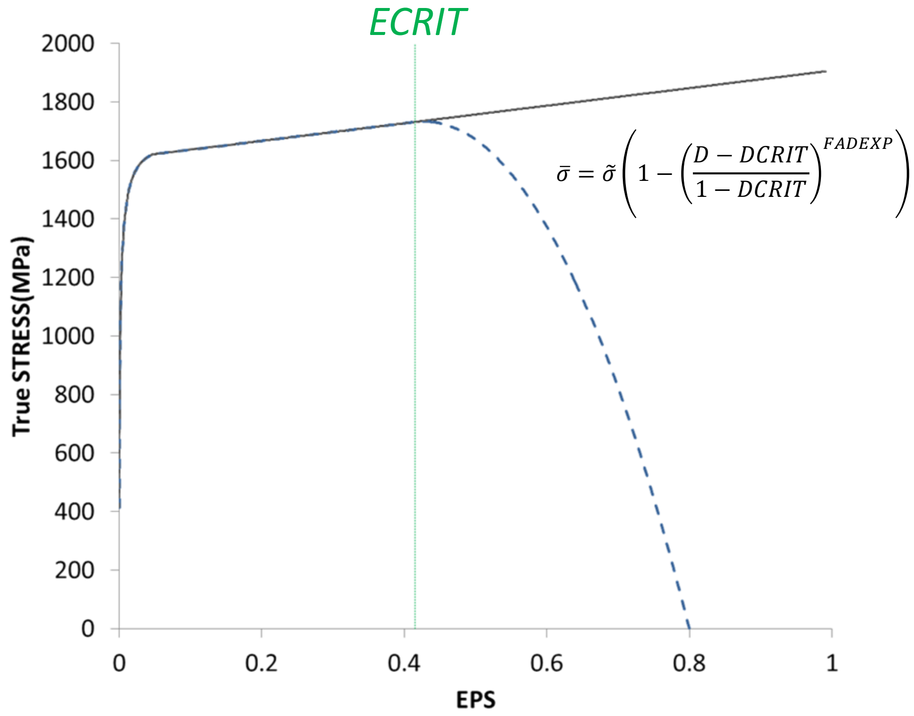
Material Instability

- Critical strain $\bar{\varepsilon}^{p}_{loc}$ depending on stress triaxiality
  - Uniaxial: ductile fracture, shear and bi-axial: brittle fracture
  - Stress triaxiality dependent critical strain(ECRIT) was made referring to FLD and other tensile tests.

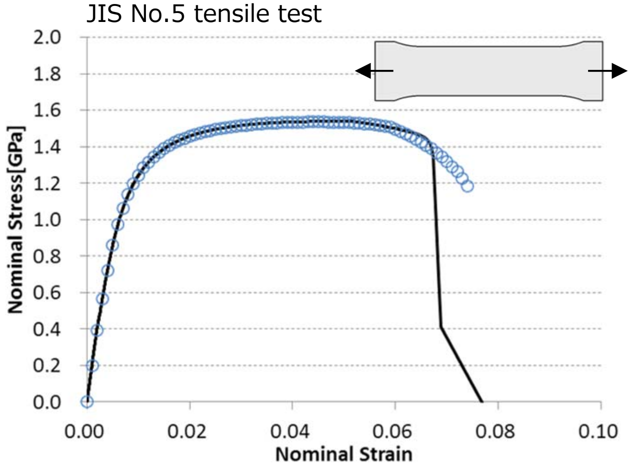


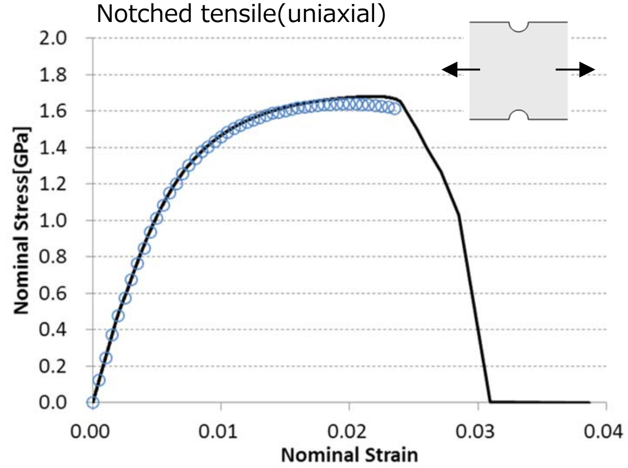


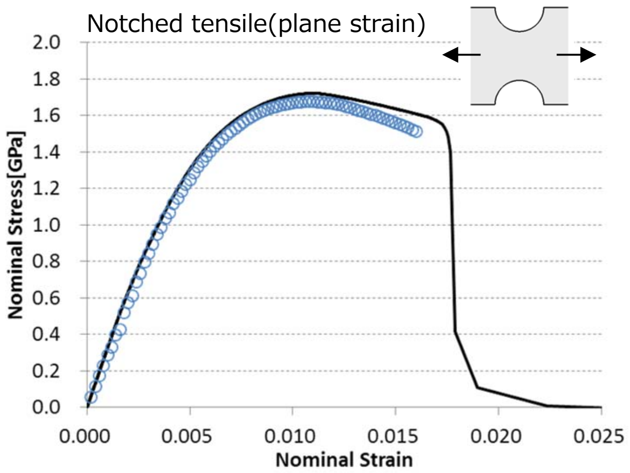
Numerical validation

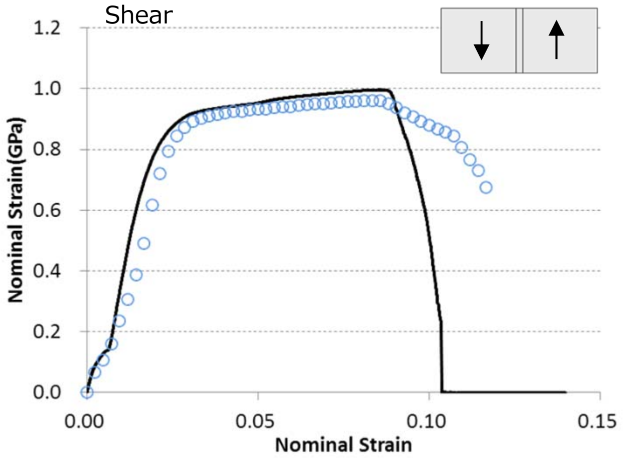
- Comparison of nominal stress – strain curves between experiment and simulation result.

Circle: experiment
Solid line: simulation









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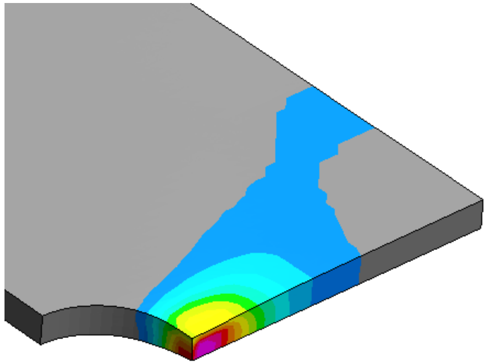
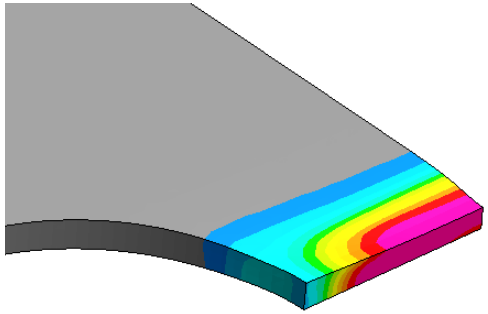
Numerical validation

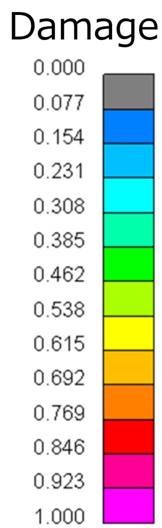
- Crack initiation point and fracture surface

Notched tensile(plane stress)

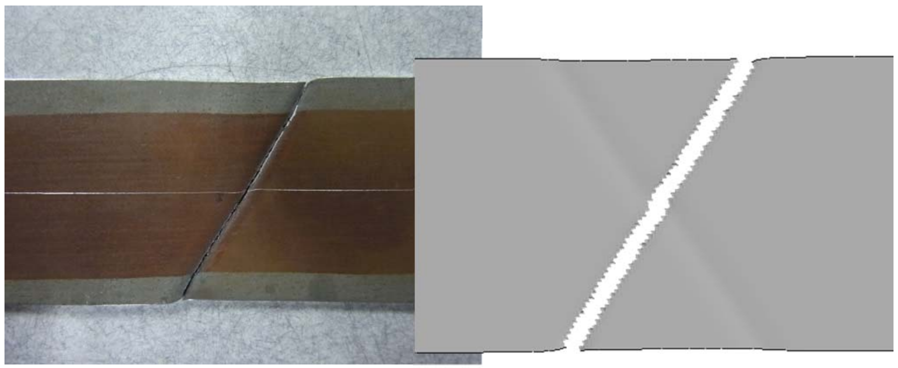


Notched tensile(plane strain)

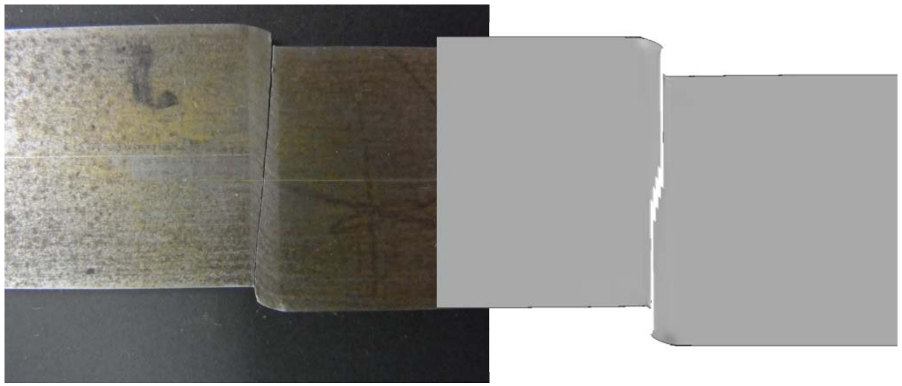




JIS No.5 tensile test

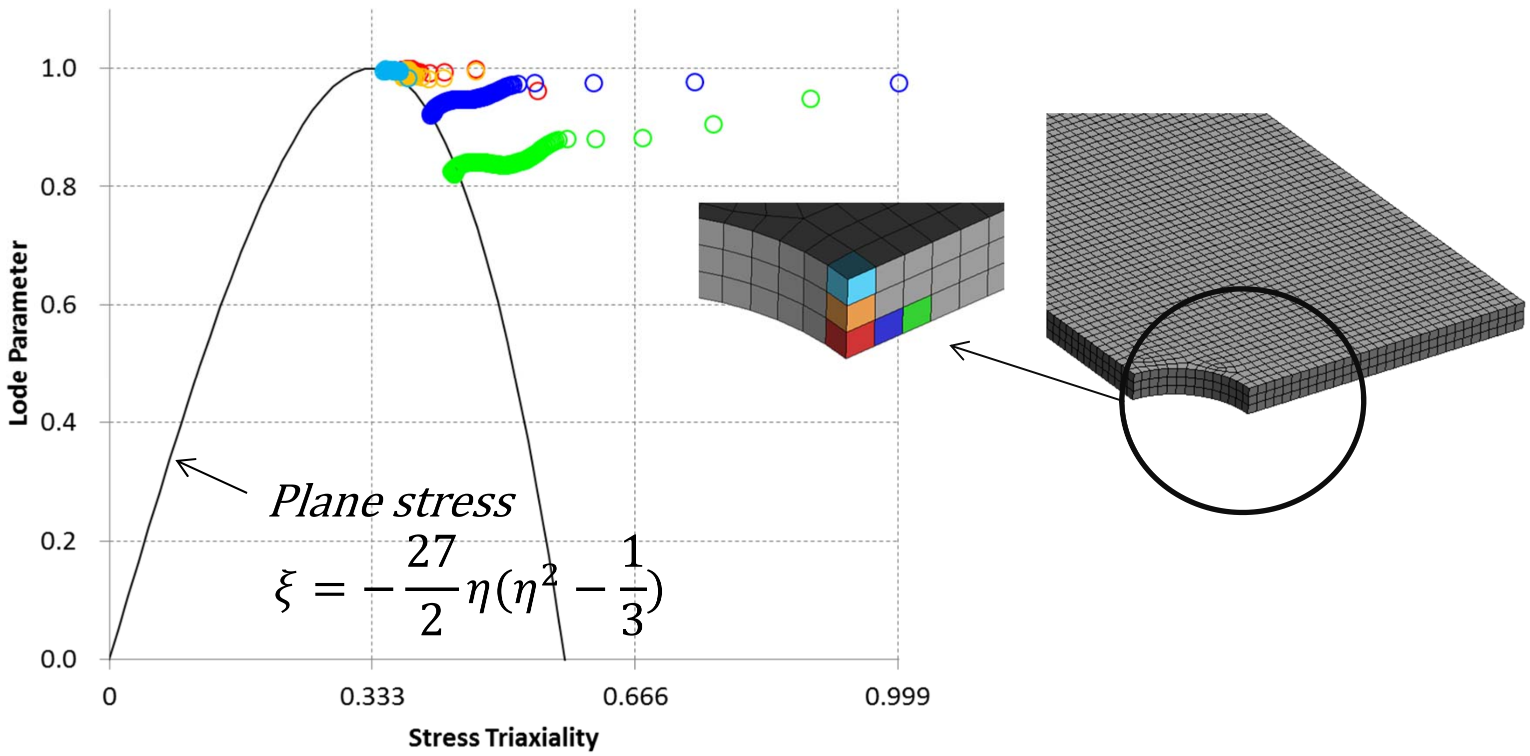


Shear



Numerical validation

- Lode parameter – plane stress relation during calculation.
  - Stress state drifted from plane stress condition.
  - Limitation of material failure prediction considering stress triaxiality only.



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Conclusion

- Calibration of failure criteria in GISSMO for metals
  - Several types of tensile experiments using PHS(TS 1500MPa grade) were conducted in order to identified failure strain in different stress states.
  - Failure strains were defined in wide range of stress triaxiality using phenomenological material failure model.
  - Material instability(critical strain) was modelled, considering to the tensile experiments and FLD(Forming Limit Diagram) of the material.
  - Numerical experiments were conducted to reproduce the tensile tests. Each result of numerical analysis is in good agreement with the failure initiation of the experimental results.