热成形钢材料卡片开发与零部件碰撞验证
Material failure characterization and validation for boron steel

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Content

- Why failure prediction and fracture model
- Material failure model with CrachFEM
- Material testing schedule
- Material card development
- Validation under crash loadcase
- Summary and outlook

Why failure prediction and fracture model

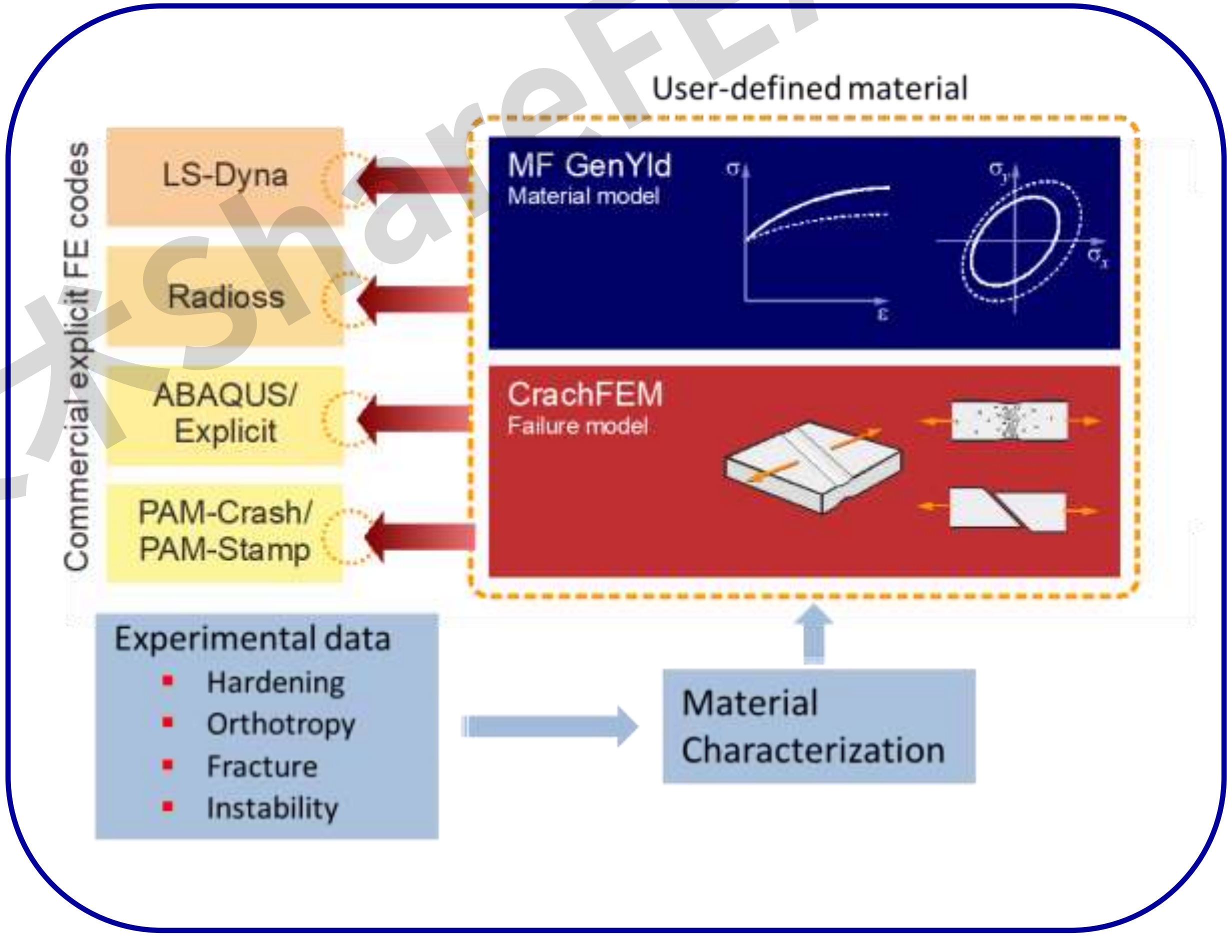
- Boron steel widely used for BIW to increase safety
- Decreasing level of failure with increasing strength
- Increased susceptibility to fracture, particularly ductile shear fracture
- Sensitive to geometrical notches
  - cutting edge, small hole, spotweld
- Advanced FE-failure model required

Courtesy of Volvo Cars

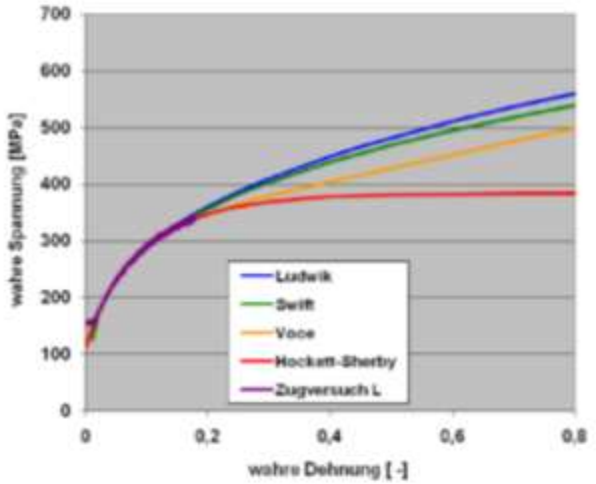
Material failure model with CrachFEM

- Comprehensive material and failure model
  - Material model: MF GenYld
  - Failure model: CrachFEM
  - User-defined material model

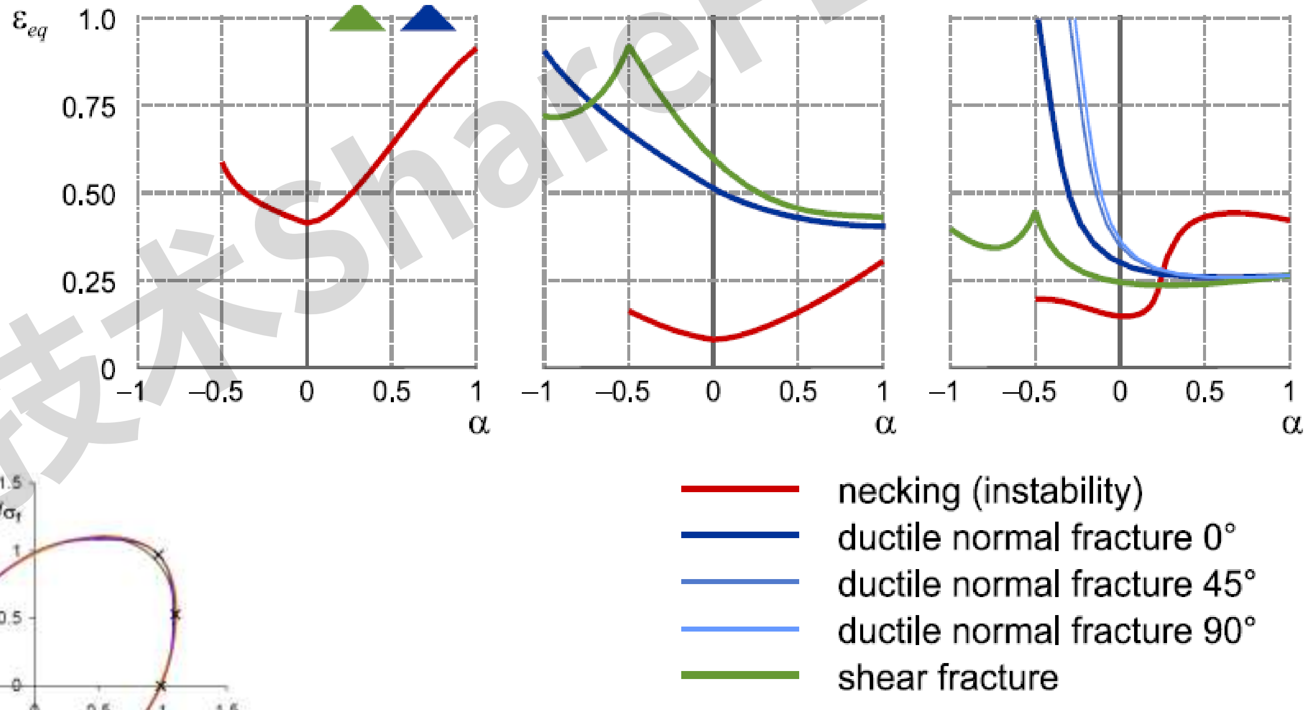
- Plasticity and fracture inextricably linked
  - Fracture strains only have meaning when they are viewed together with plasticity information
  - Good fracture predictions require using a good plasticity model



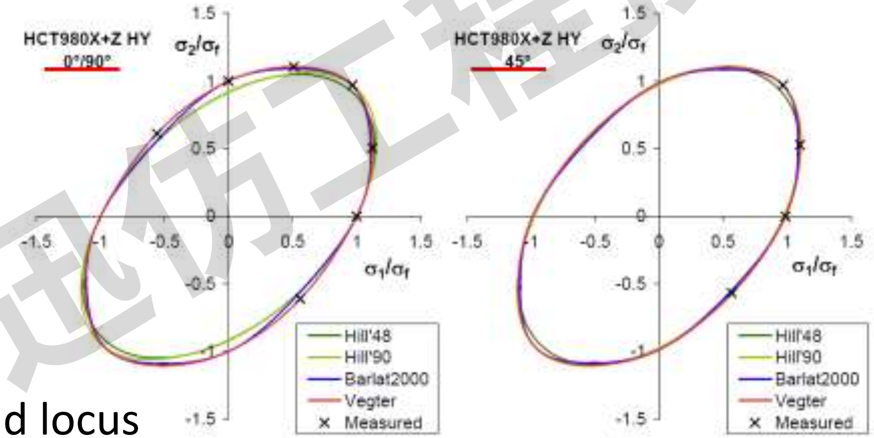
Material failure model with CrachFEM



Plastic hardening



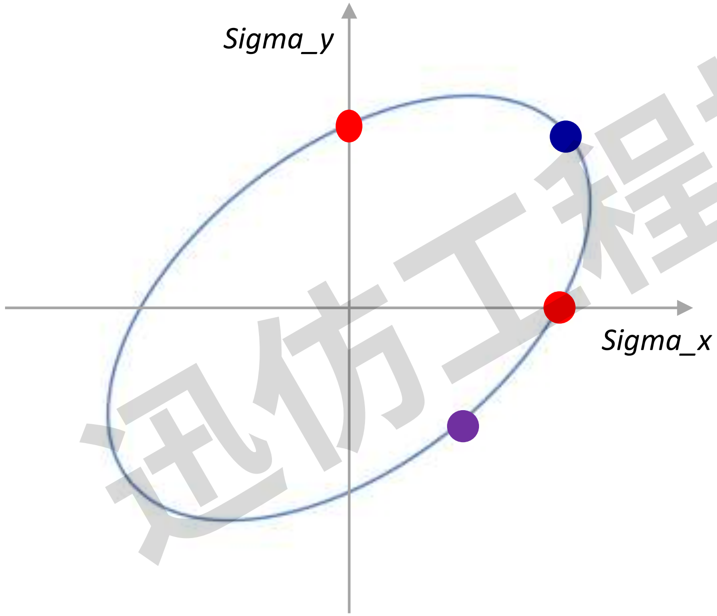
Fracture curves



Yield locus

Material testing schedule

- Material plasticity
  - Uniaxial tensile test ●
    - No strain rate effect for Boron steel
  - Torsion or shear test ●
  - Layered compression ●



Material testing schedule

Torsion

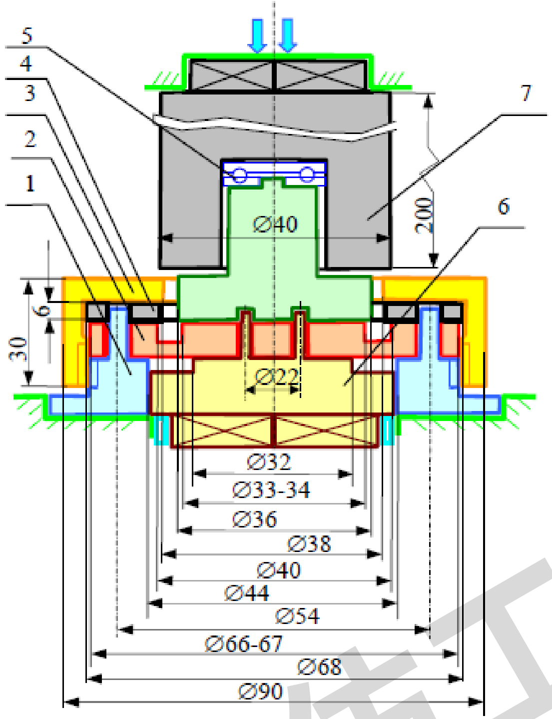


Figure 7. Torsion device:1 – frame; 2 – specimen; 3 – external press-holder; 4 –washer –press-holder; 5 – thrust bearing; 6 – turn cylinder; 7 –internal press-holder

Layered compression

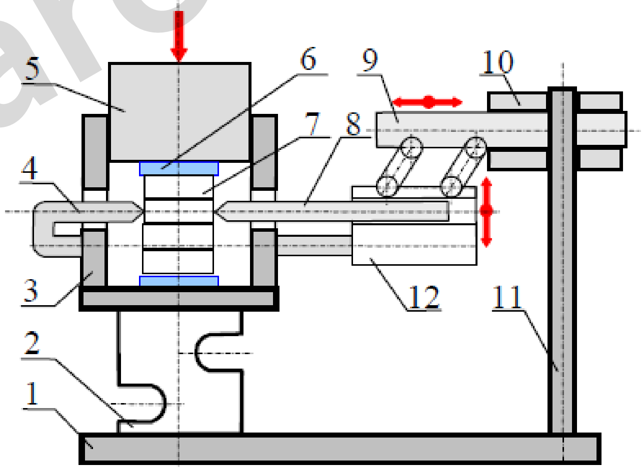
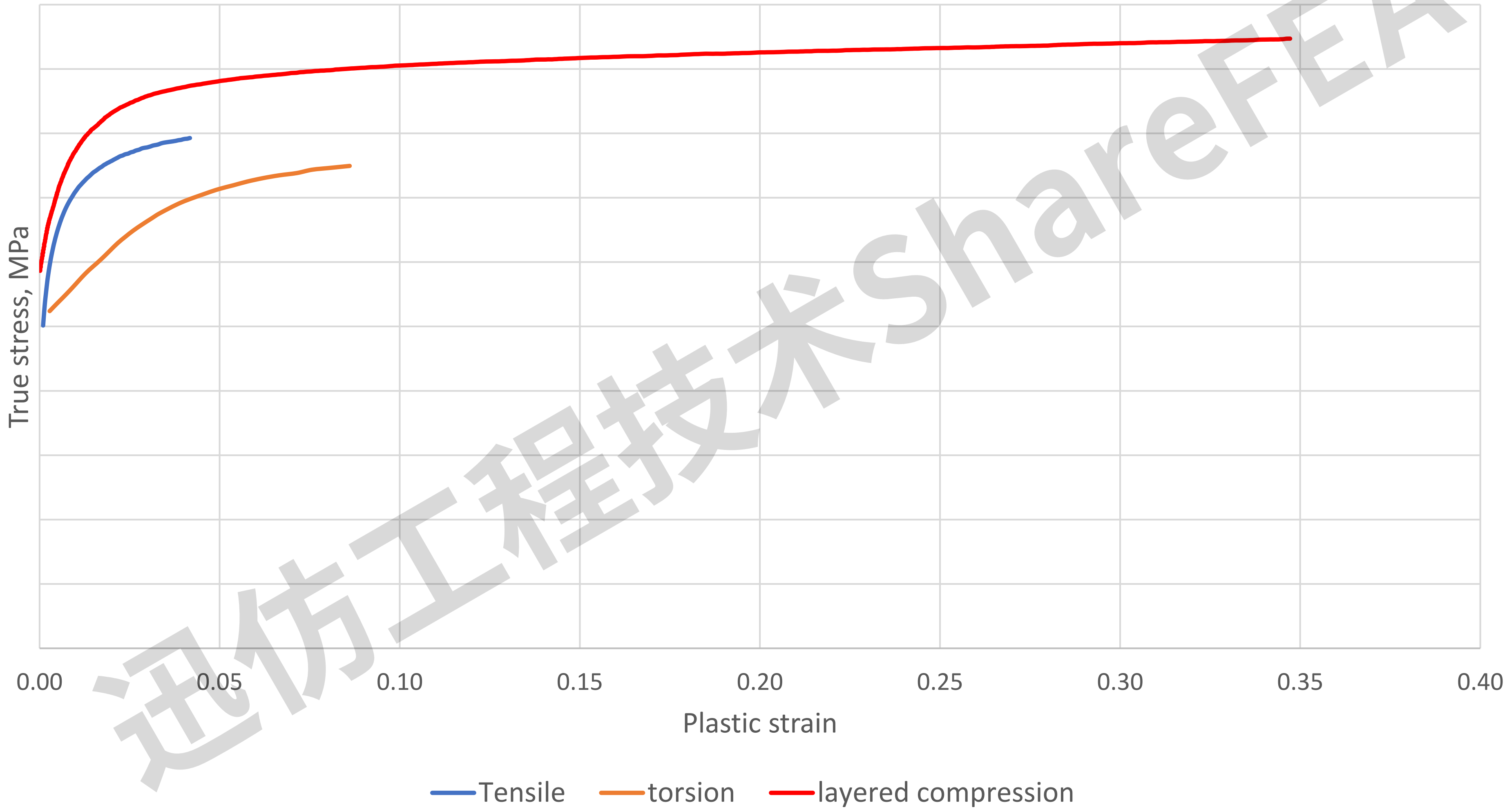


Figure 5

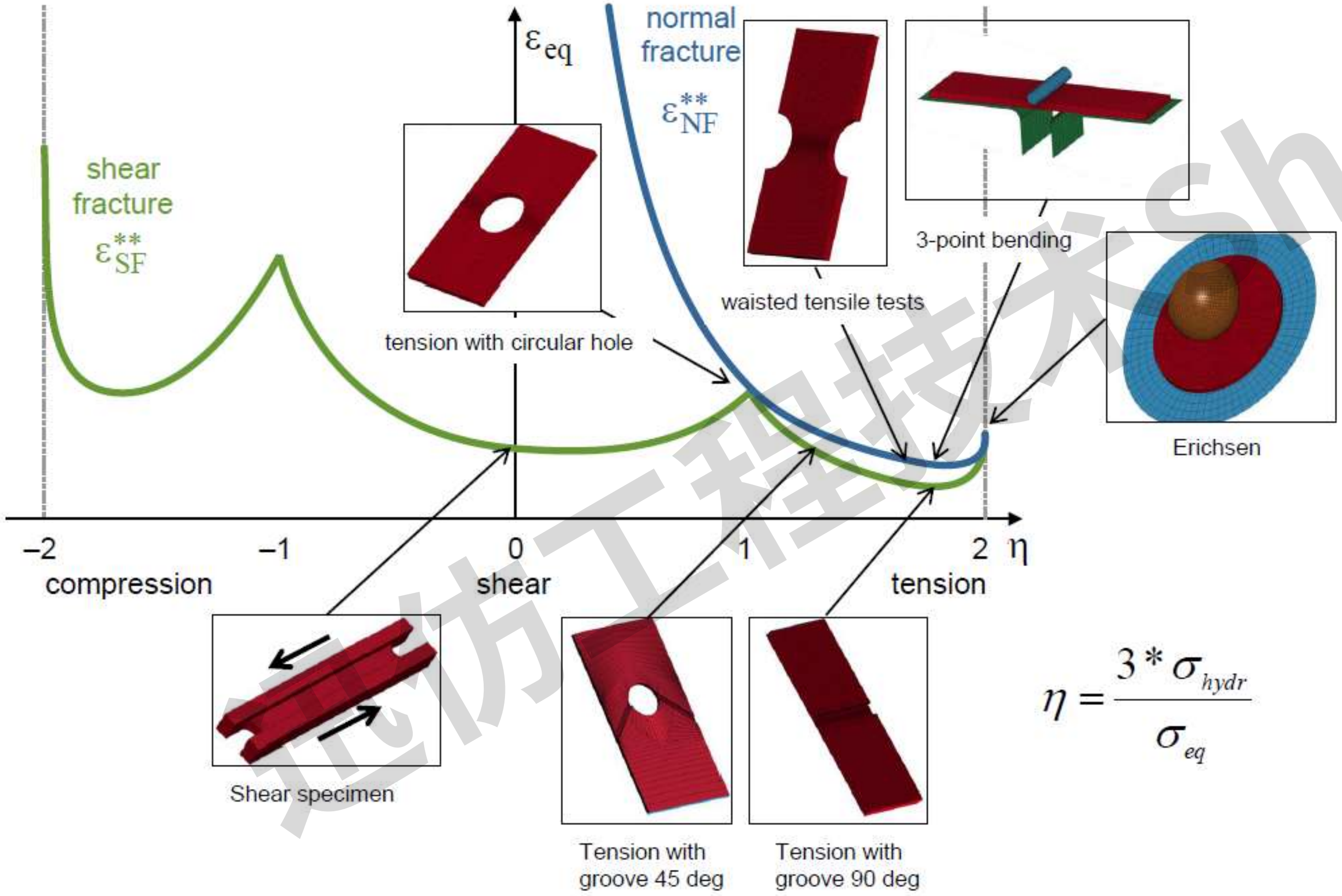
1 – base plate; 2- force transducer; 3- pilot pin; 4-measured staple; 5-punch; 6-TEFLON films of thickness 0.4mm; 7 –disk of layered specimen; 8- deformation transducer; 9 –movable rod; 10- support; 11 – post; 12- movable support

Material testing schedule



Material testing schedule

- Fracture limit curves



$$\eta = \frac{3 * \sigma_{hydr}}{\sigma_{eq}}$$

Ductile normal fracture

$$\eta = -3 * p / \sigma_M \qquad \beta = (1 - s_{NF}\, \eta) / \nu$$

$$\nu = \sigma_1 / \sigma_M \qquad \varepsilon_{eq}^{**} = d \cdot e^{q \cdot \beta}$$

Ductile shear fracture

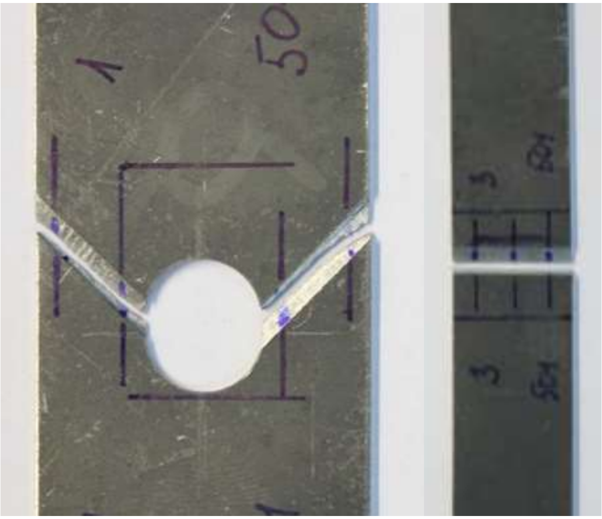
$$w = \frac{\tau_{max}}{\sigma_M} \qquad \theta = (1 - k_{SF} \cdot \eta) / w$$

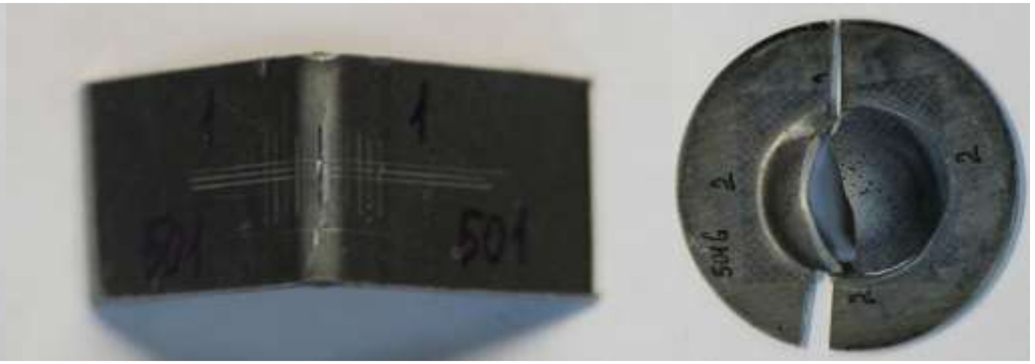
$$\varepsilon_{eq}^{**} = \frac{\varepsilon_{SF}^{+} \sinh\left(f\left(\theta - \theta^{-}\right)\right) + \varepsilon_{SF}^{-} \sinh\left(f\left(\theta^{+} - \theta\right)\right)}{\sinh\left(f\left(\theta^{+} - \theta^{-}\right)\right)}$$

Material testing schedule

Fracture Tests	Theory		B1500HS
	Normal	Shear	
Tension of specimens with groove 45 deg			shear
Tension of specimens with groove 90 deg			shear
Tension of specimens with hole			shear-normal
Tension of waisted specimens			shear
Unibiaxial tension- Erichsen's test			shear
Shear test			shear
Bend			normal

Material testing schedule





Material testing schedule

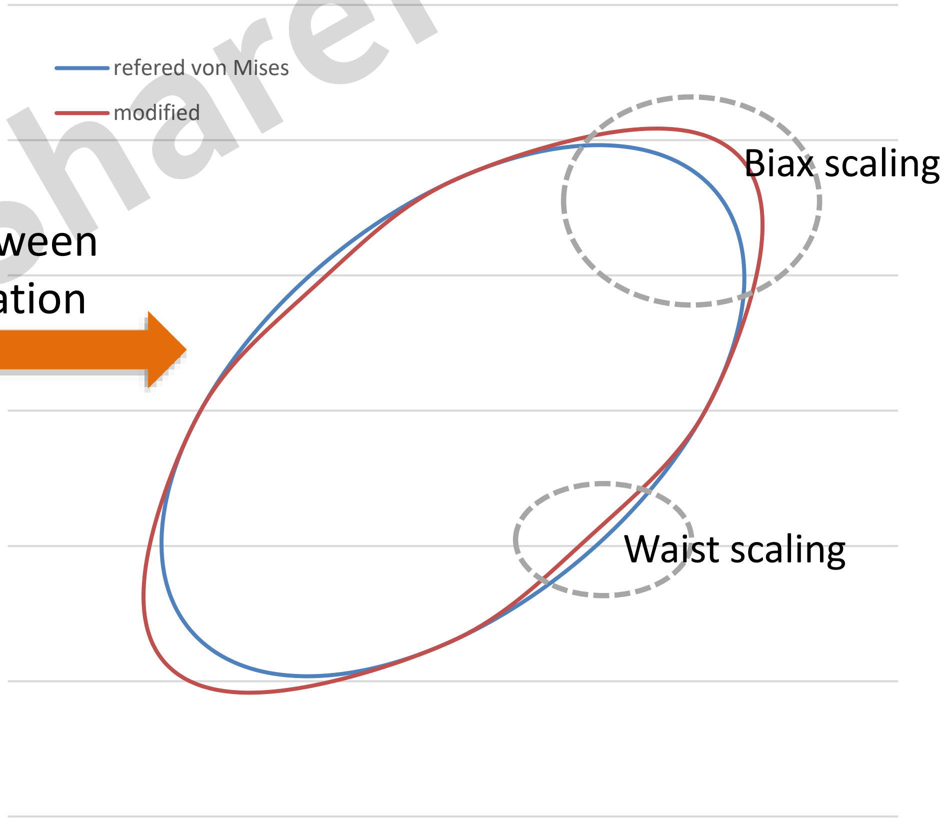
- Tips
  - Steel plates should mark the rolling direction
  - Quality of quenched steel plates should be checked
  - Perform microhardness measurement in the 4 corners of the plates

Material card development

- Identification of yield locus

Tensile under 0/45/90 deg
Torsion (1.06)
Layered compression (0.89)

Fitting of yield loci between
1% and uniform elongation

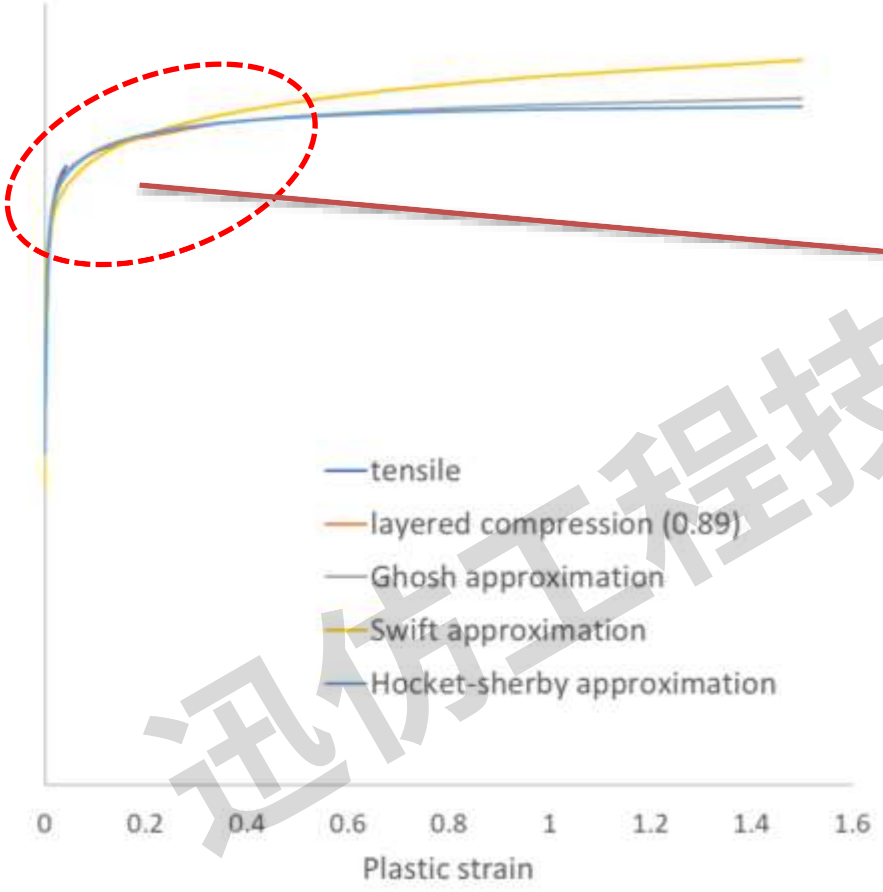


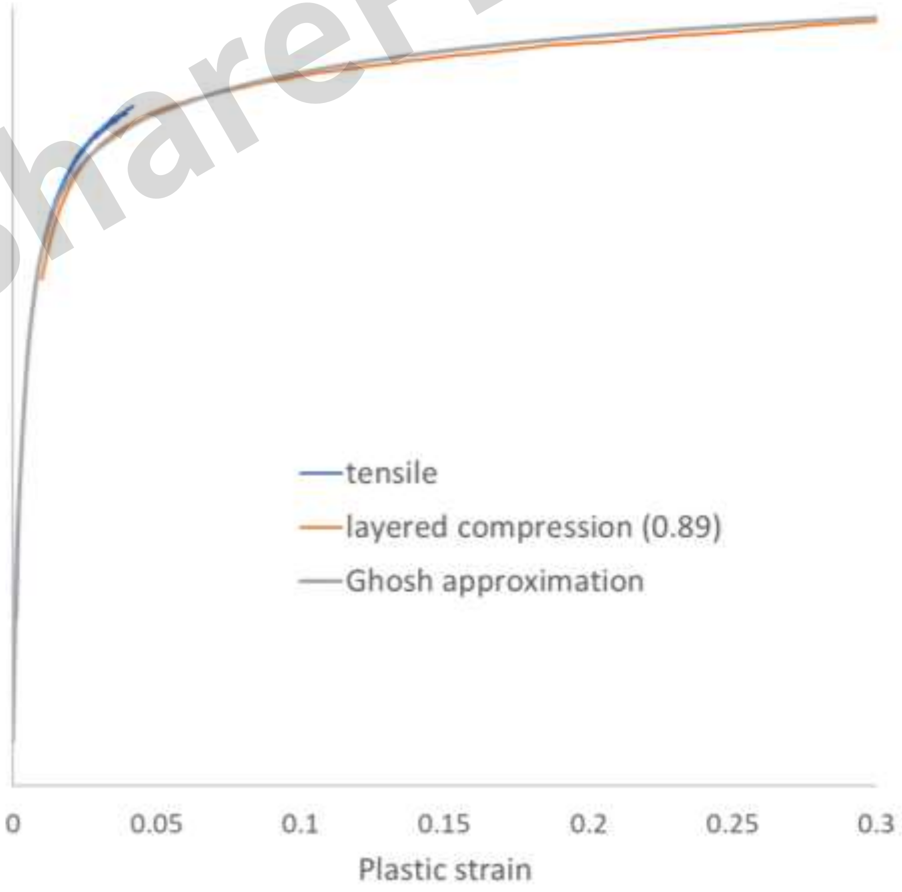
Mises with biax and waist scaling

Material card development

- Identification of strain hardening

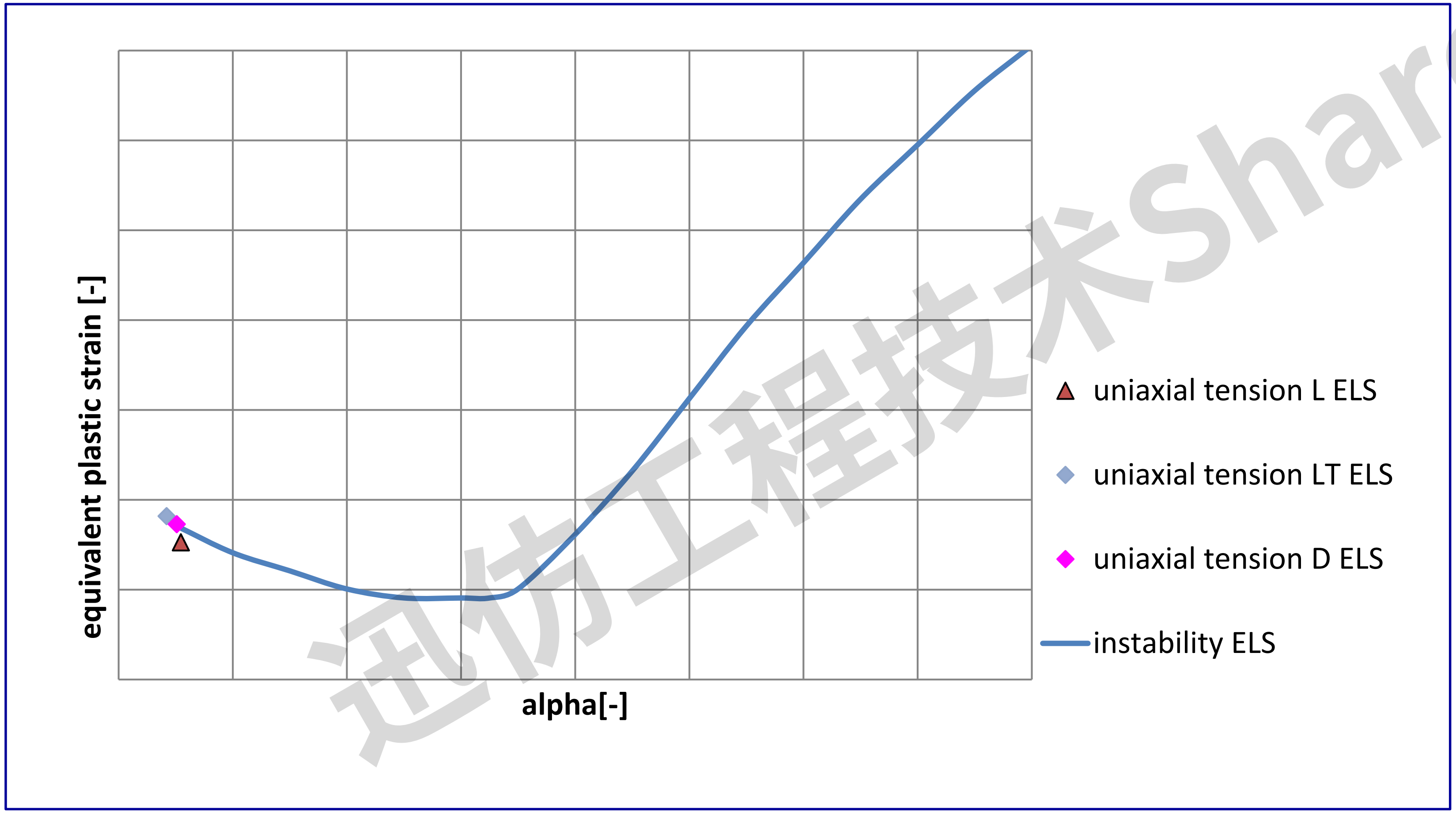
Ghosh extended: s = a* (e0 +eps)^n + k + r*exp(-q*eps)
Hocket-sherby extended: s = a - (a - s0)*exp(-c*phi^n) + r*exp(-q*phi)
Swift: s = a* (e0 +phi)^n



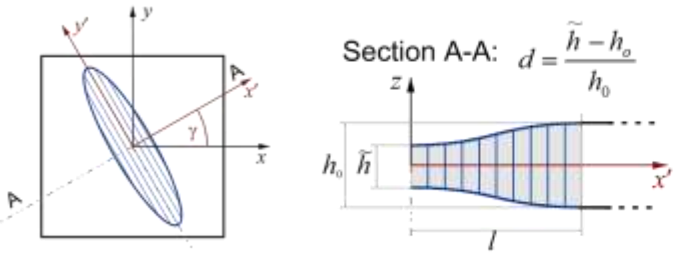


Material card development

- Derivation of CrachFEM parameters for localized necking (FLC)

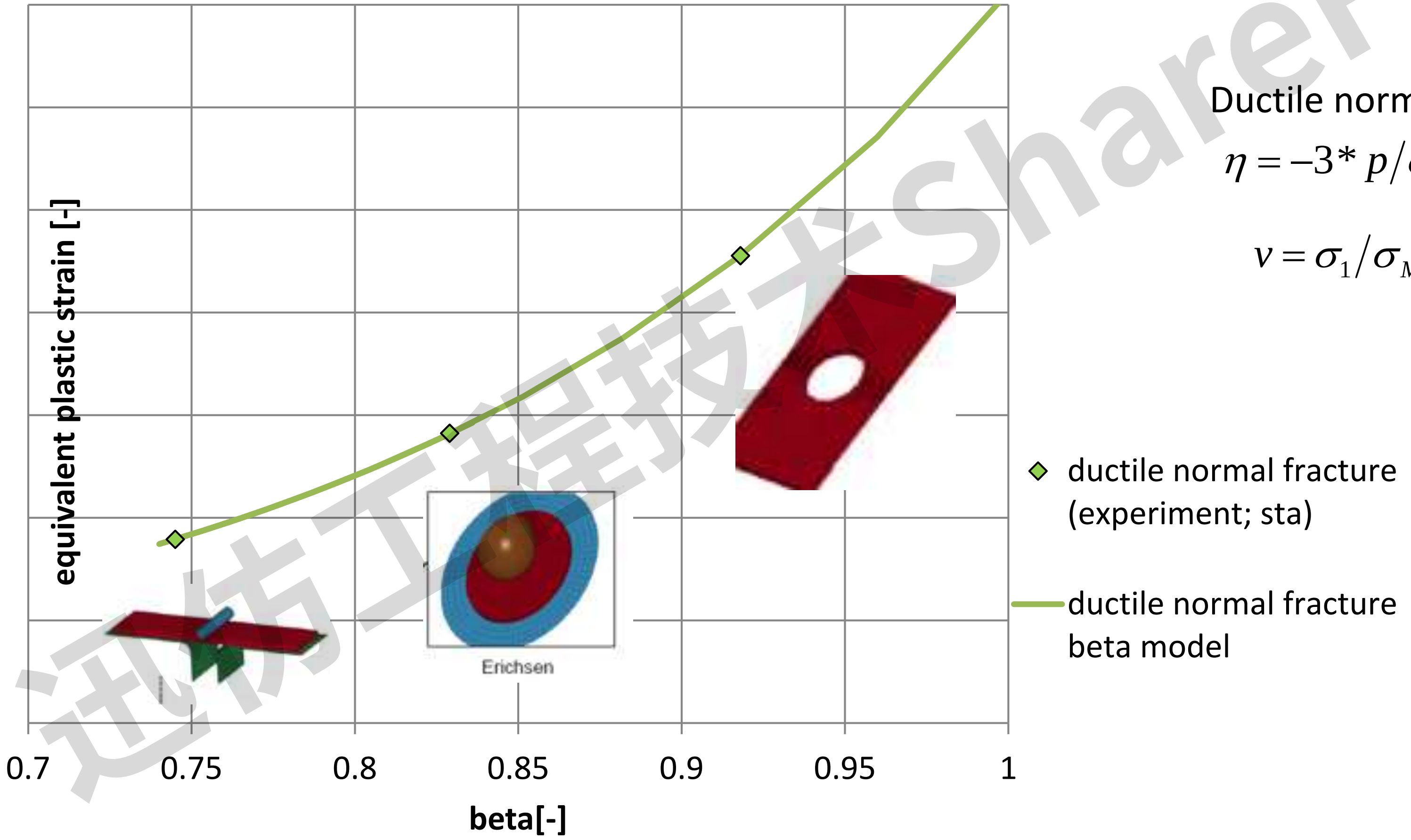


– Crach requires the following data:
  - Anisotropy (Hill 1948)
  - Total hardening
  - Kinematic hardening (Backhaus)
  - Strain rate sensitivity *m*
  - Initial inhomogeneity *d*



Material card development

- Approximation of fracture curves for ductile normal fracture – Beta model



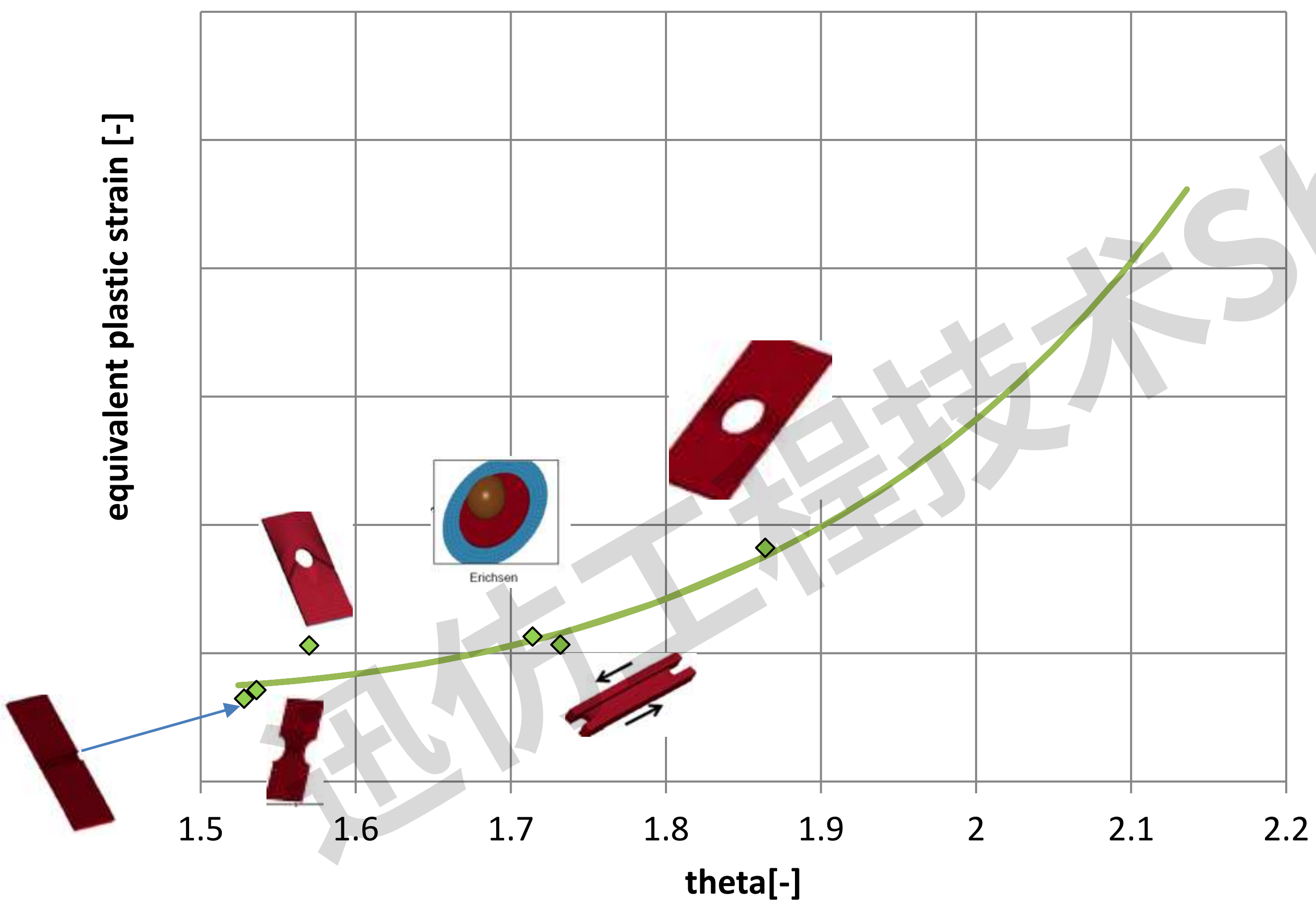
Ductile normal fracture

$$\eta = -3 * p / \sigma_M \qquad \beta = (1 - s_{NF}\,\eta)/\nu$$

$$\nu = \sigma_1 / \sigma_M \qquad \varepsilon_{eq}^{**} = d \cdot e^{q \cdot \beta}$$

Material card development

- Approximation of fracture curves for ductile shear fracture – Theta model



Ductile shear fracture

$$w = \frac{\tau_{max}}{\sigma_M} \qquad \theta = (1 - k_{SF} \cdot \eta)/w$$

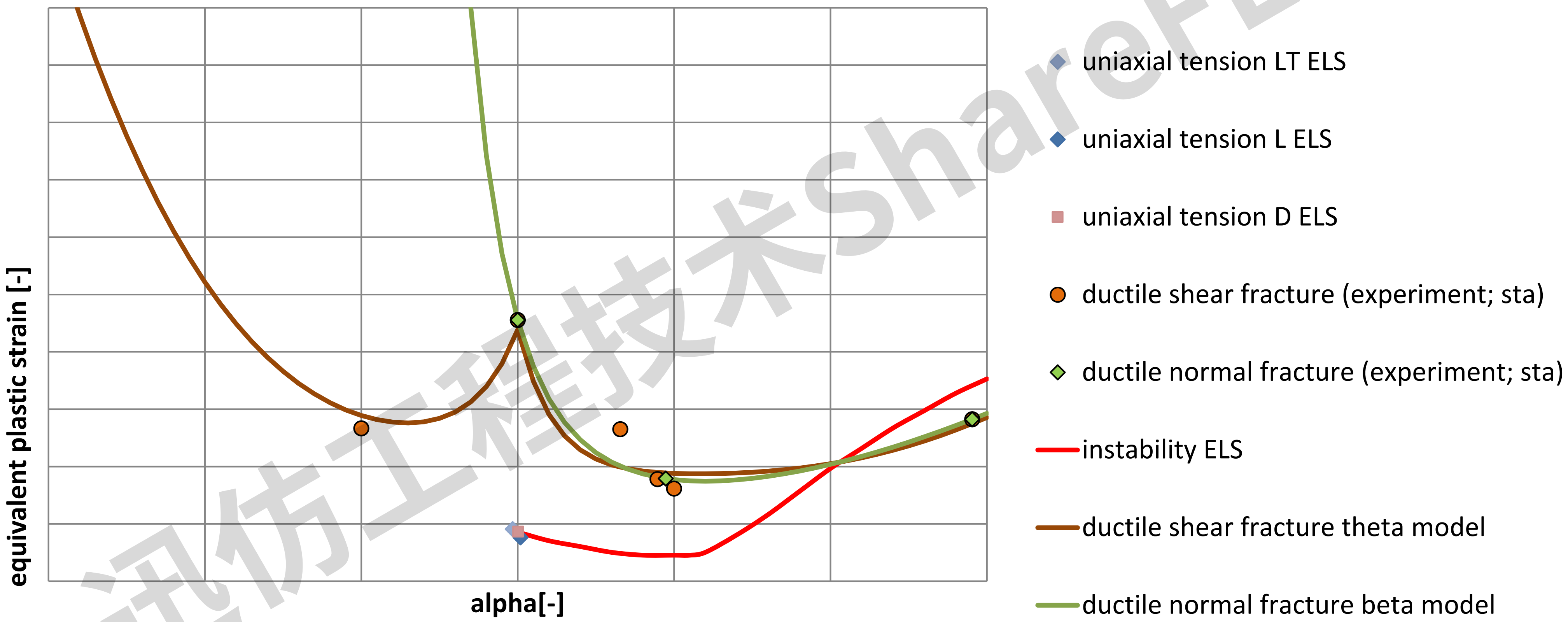
$$\varepsilon_{eq}^{**} = \frac{\varepsilon_{SF}^{+} \sinh\left(f\left(\theta - \theta^{-}\right)\right) + \varepsilon_{SF}^{-} \sinh\left(f\left(\theta^{+} - \theta\right)\right)}{\sinh\left(f\left(\theta^{+} - \theta^{-}\right)\right)}$$

◇ ductile shear fracture (experiment; sta)

— ductile shear fracture theta model

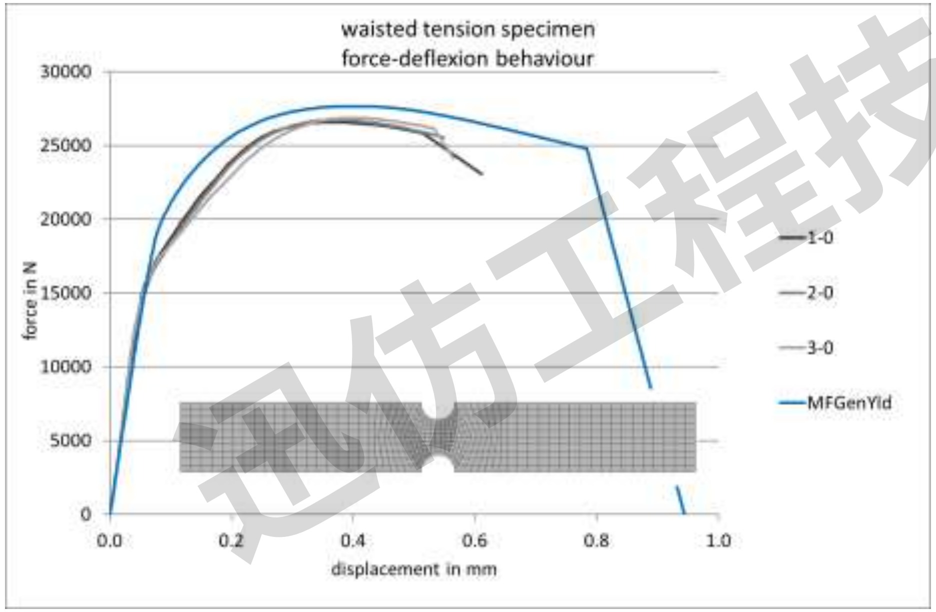
Material card development

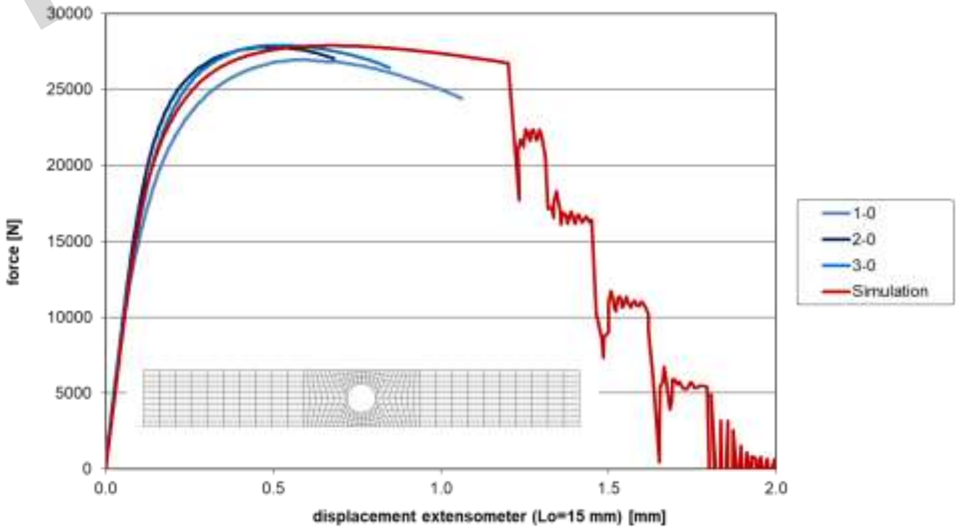
- Fracture limit curves (in condition of plane stress status)



Material card development

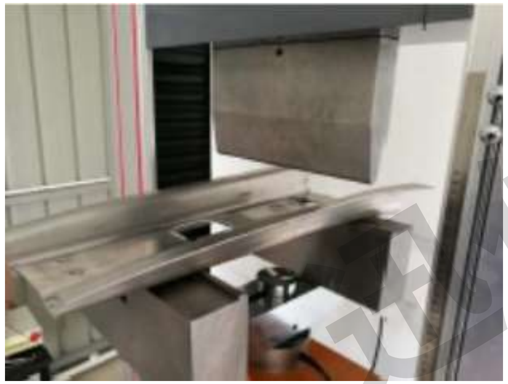
- Material tests simulation and calibration
  - Waisted tension
  - Tension with hole

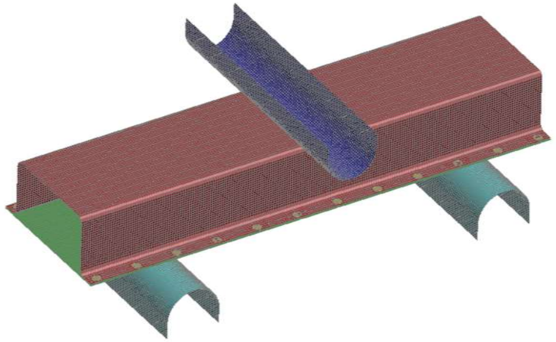


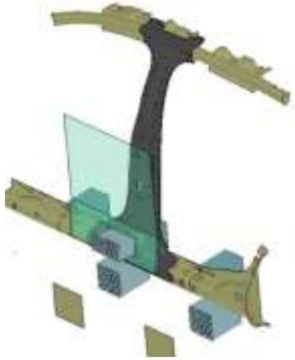


Validation under crash loadcase

- 3-point bending
  - Quasi-static
  - Dynamic

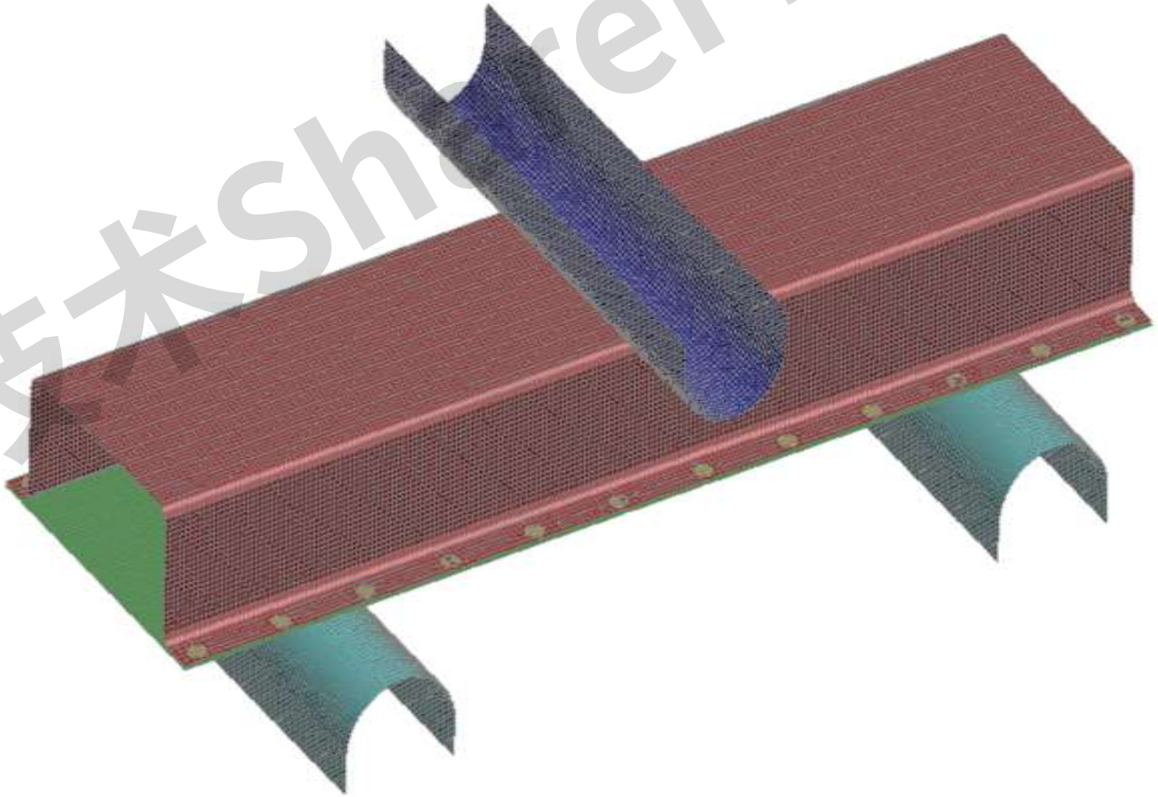






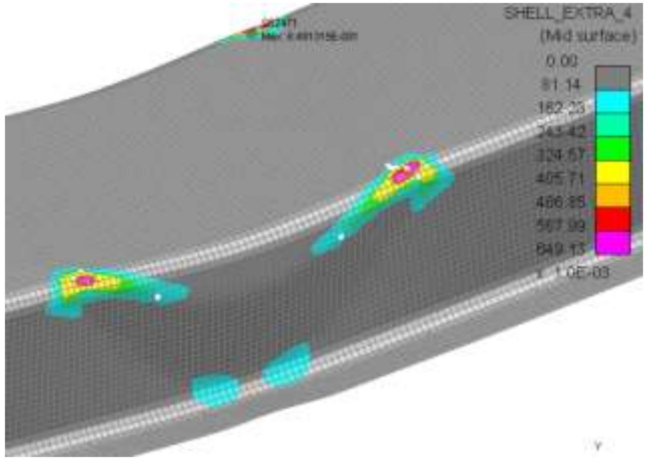
Validation under crash loadcase

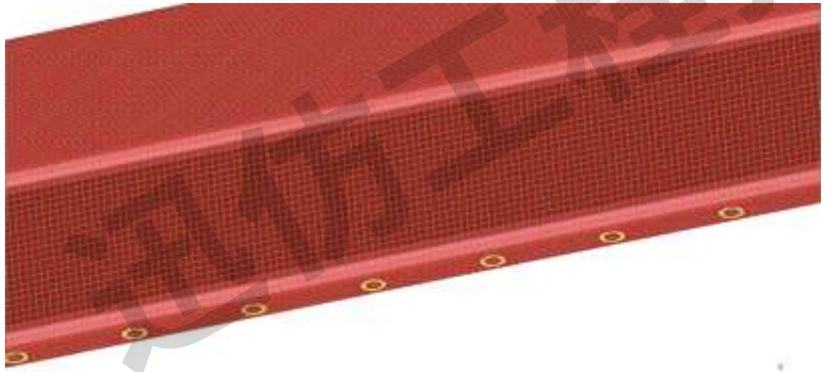
- Dynamic bending simulation
  - Boron steel: 1.45mm
  - Back plate: DP590, 1.5mm
  - ELFORM=2
  - Mesh sizing=2mm
  - Drop mass =70kg
  - Velocity=12.5m/s

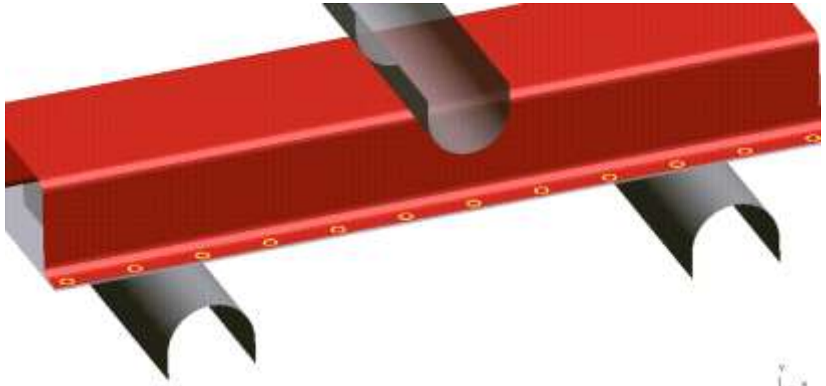


Validation under crash loadcase

- Simulation vs. test



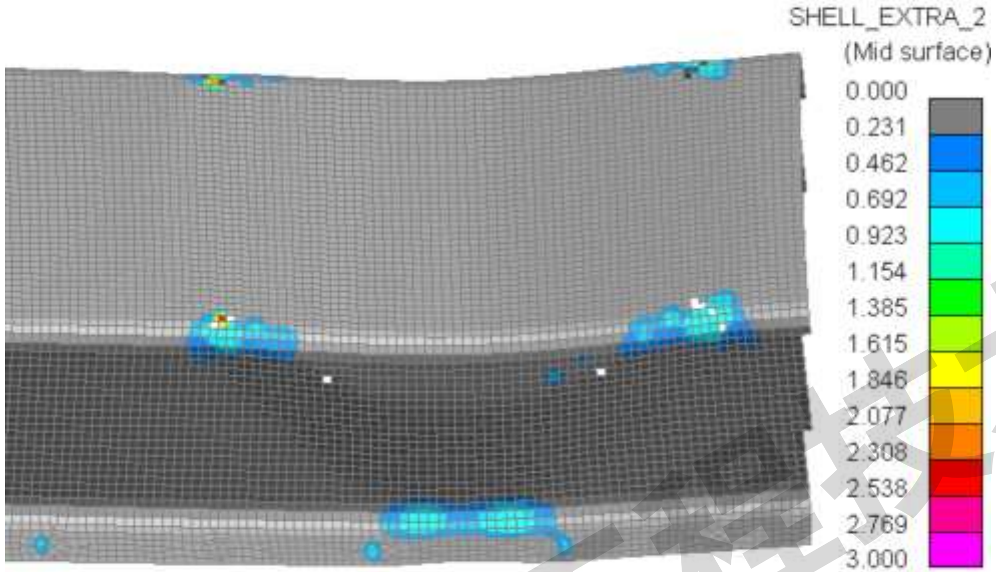


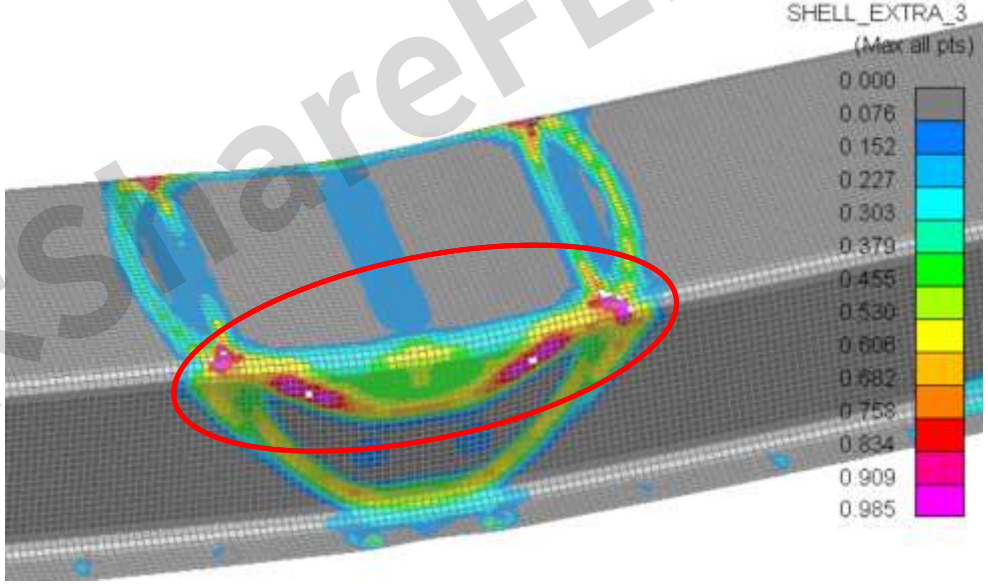


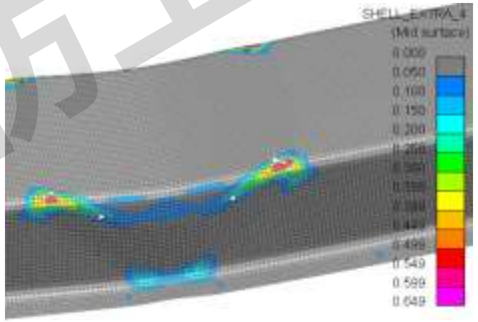
Deformation scaling 0.5

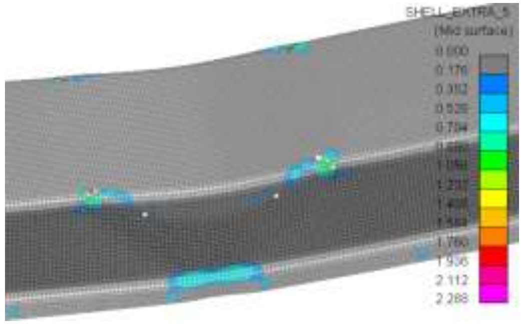
Validation under crash loadcase

- Failure mainly caused by ductile normal fracture



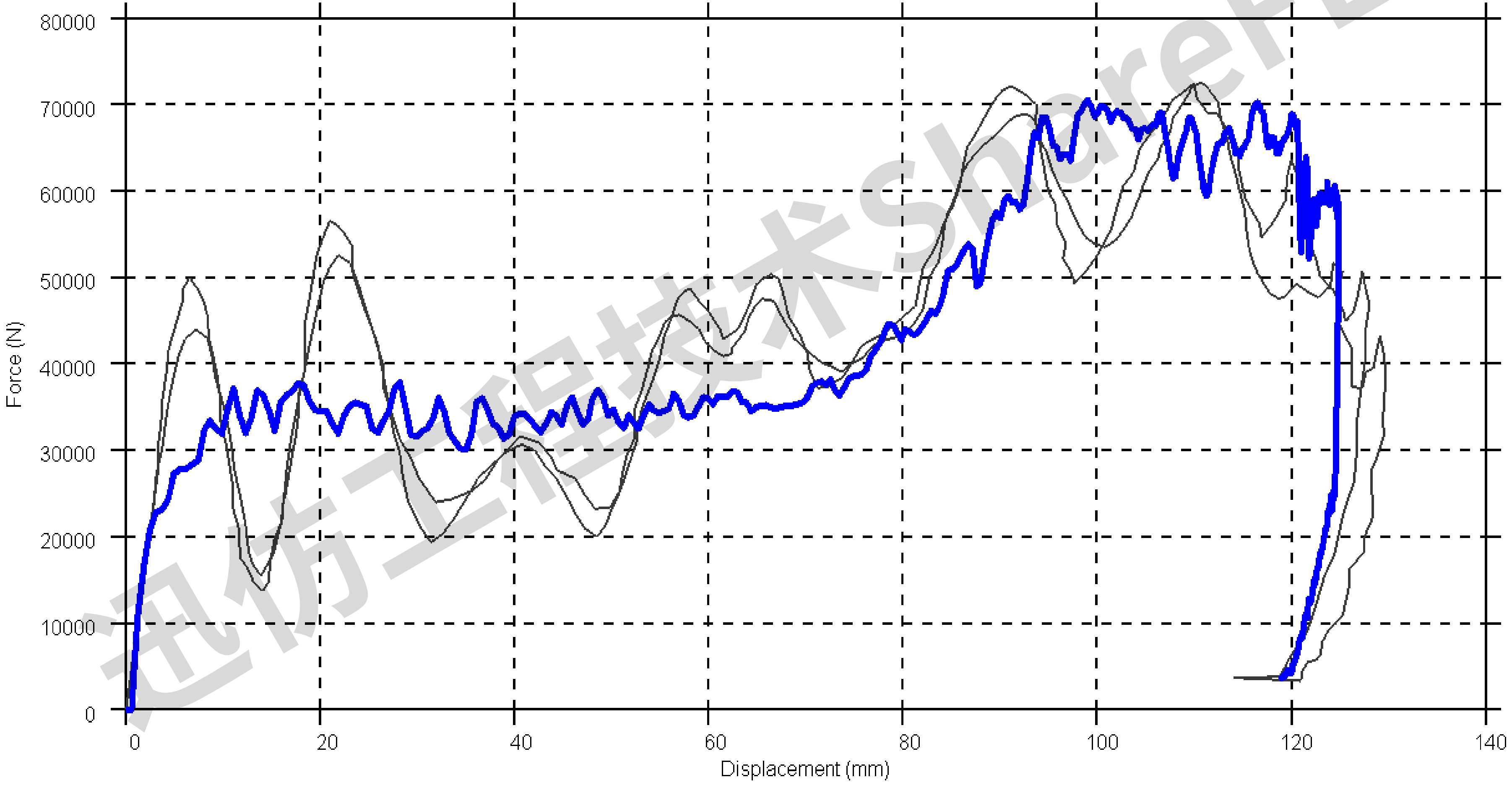






Validation under crash loadcase

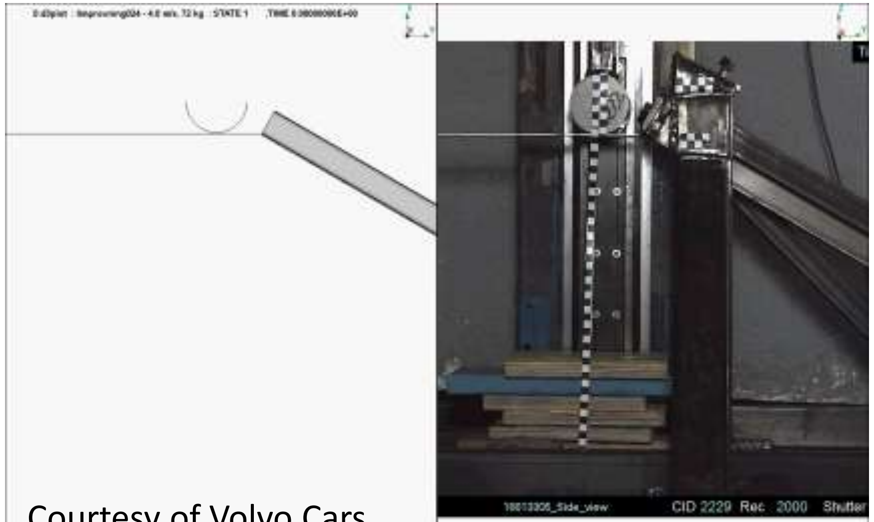
- Force-displacement comparison



Summary and outlook

- CrachFEM material model shows an efficient and close-to-application of fracture characterization and modeling of modern steel materials
- Introduce material testing and theory study schedule for boron steel
- 3-point bending simulations show good correlation to experiments
- Small mesh sizing is recommended to predict failure which increases the crash model complexity

- *Spotweld HAZ modeling for crash simulation*
- *Work with potential partners to study structural design and optimization with boron steel to avoid failure*



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