GREAT DESIGNS IN STEEL

ON TRUE FRACTURE STRAIN (TFS) OF AHSS SHEETS: MEASUREMENT AND DERIVATION

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ACKNOWLEDGEMENT

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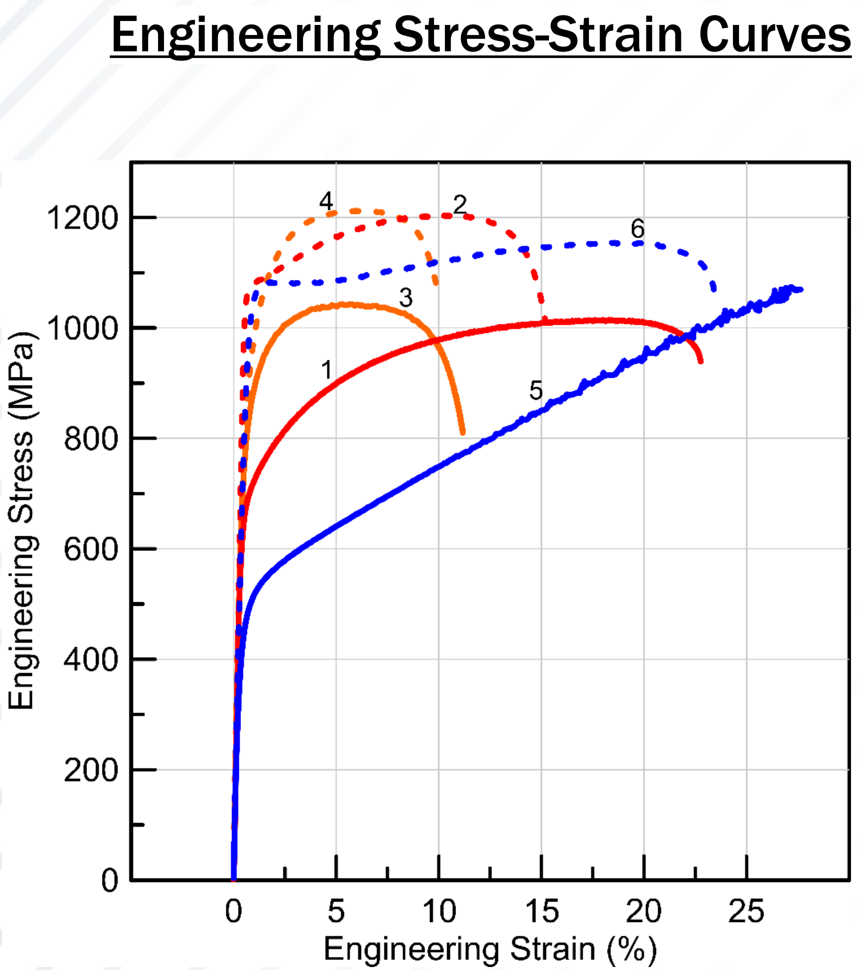
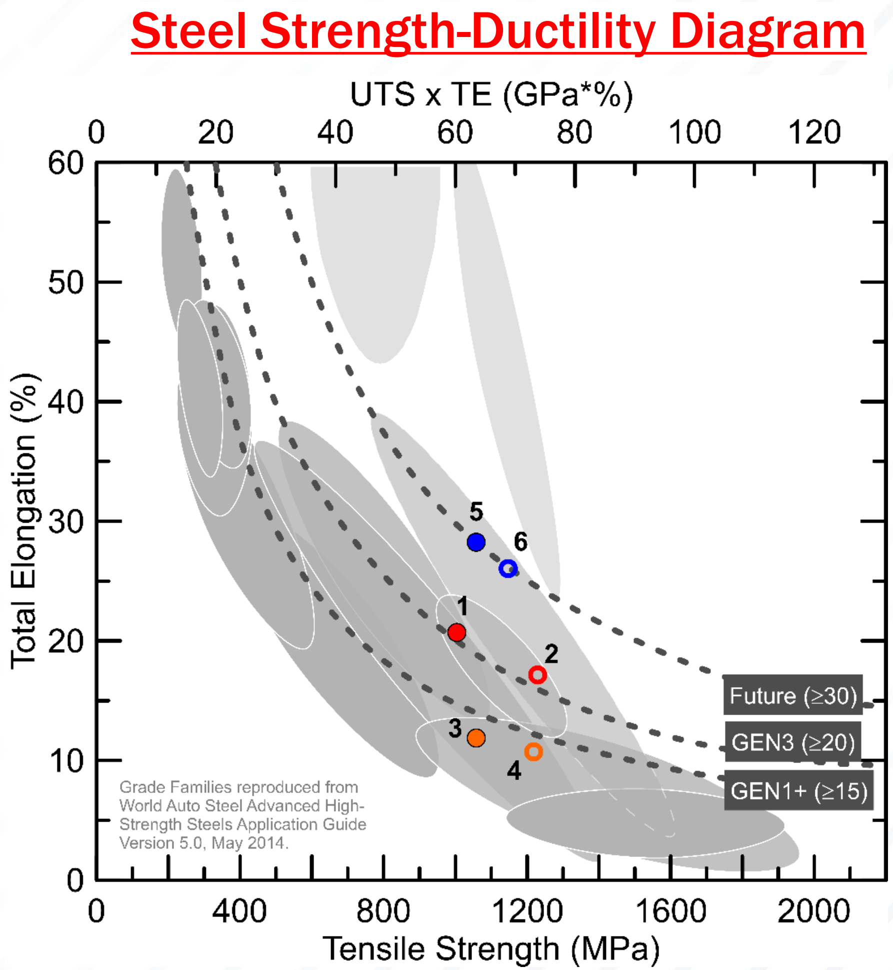
FROM TE VS. UTS …

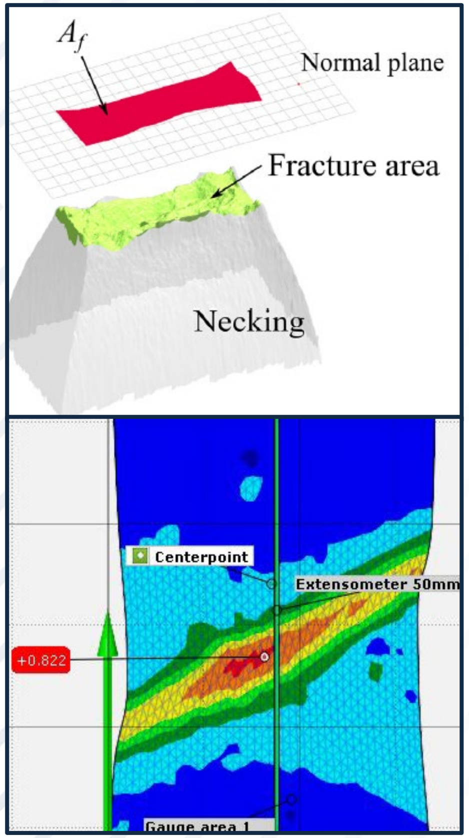


TE



UTS

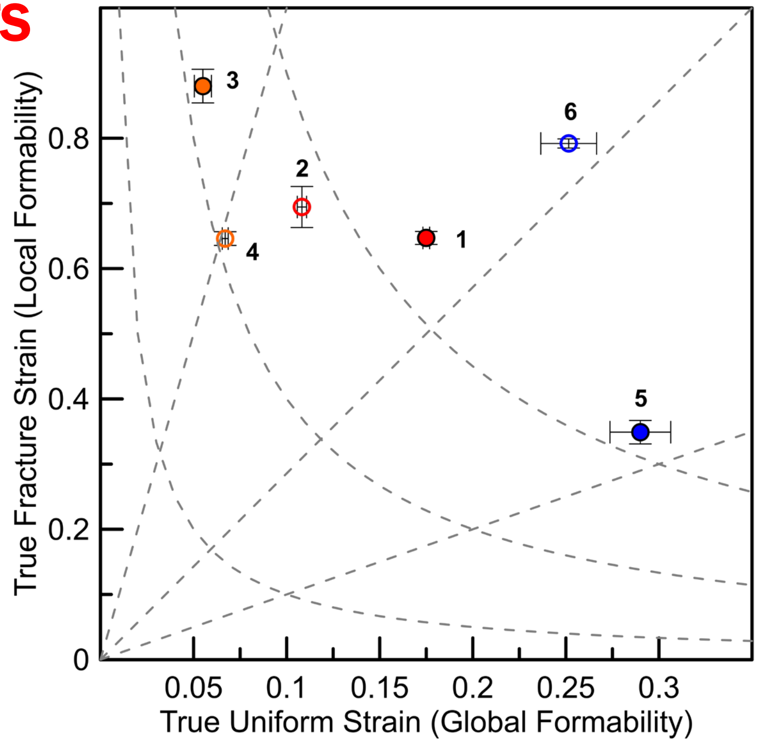
… TO TFS VS. UE



Local-Global Formability Diagram

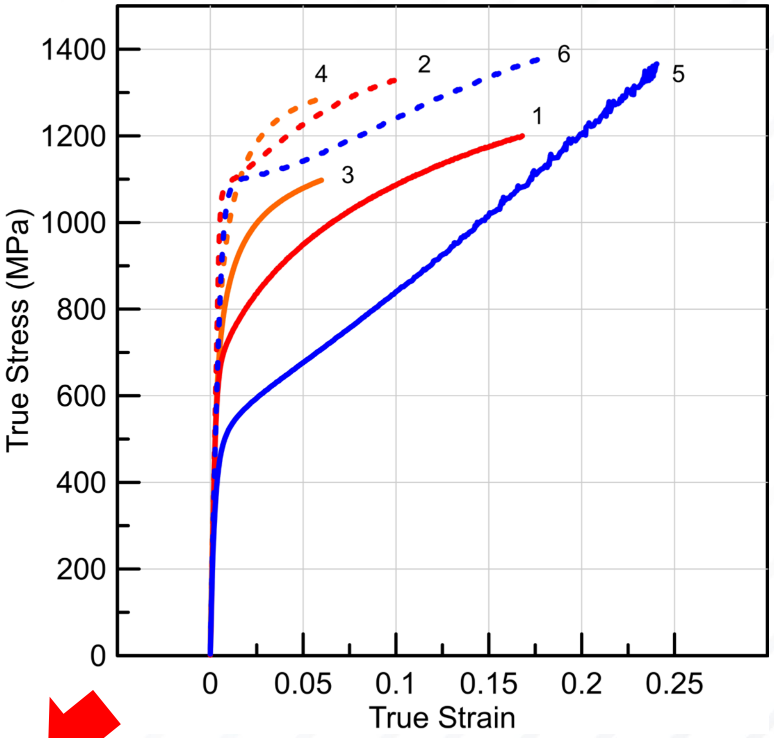
(Fracture vs. Necking Resistance)

TFS



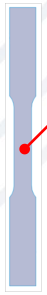
UE

True Stress-Strain Curves

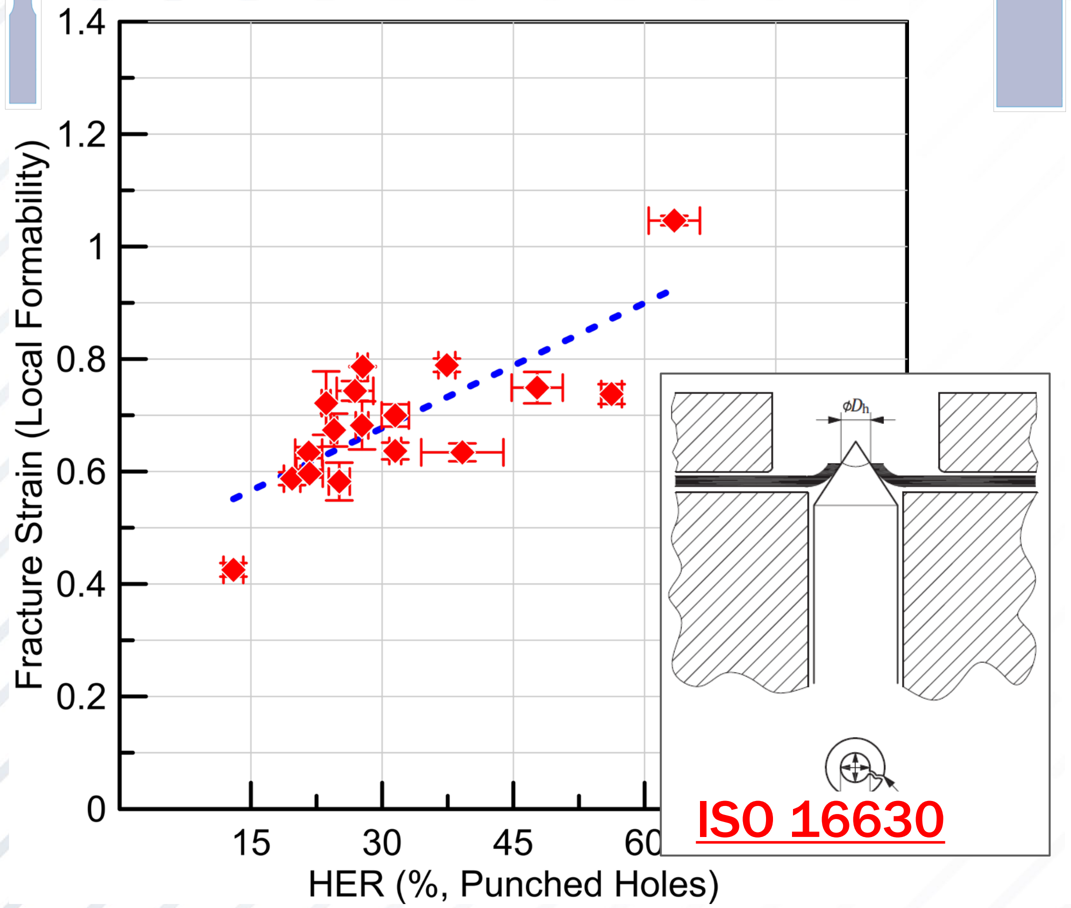


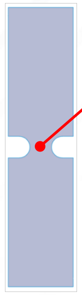
$\approx n_{terminal}$ → Keeler-Brazier equation → FLC

TFS FOR MAT. SELECTION & COMPARISON

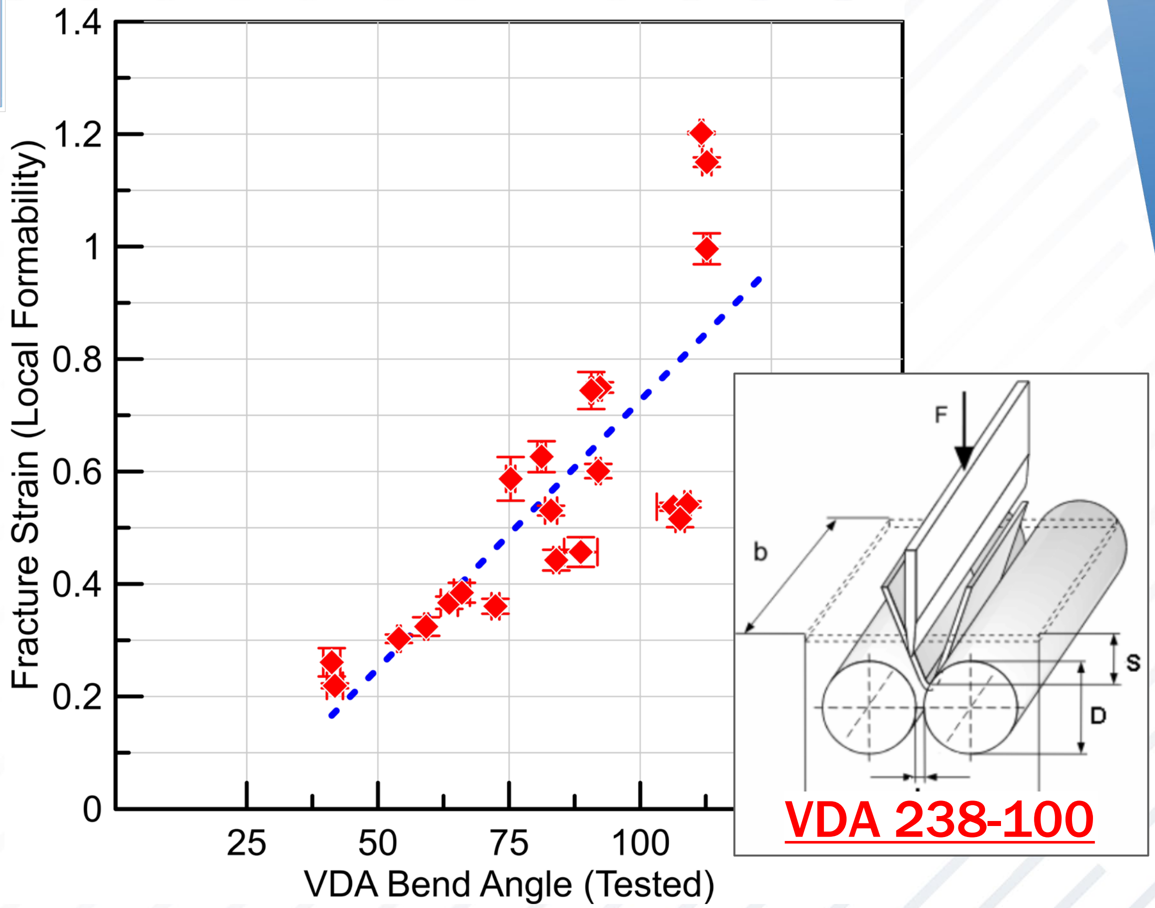


TFS from uniaxial tension test results of various 800-1700 MPa grades





TFS from notch sample tension test results of various 800-1700 MPa grades

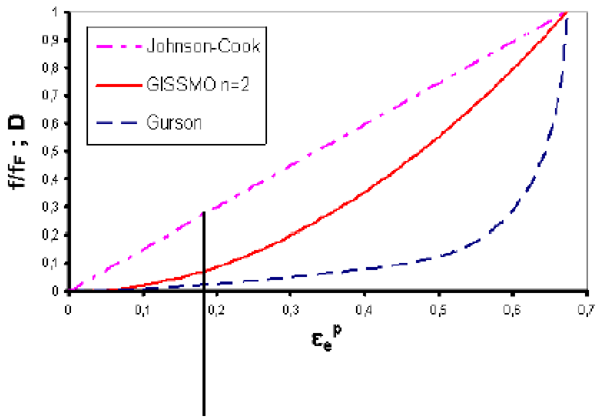


TFS FOR MODELING & SIMULATION

GISSMO: Generalized Incremental Stress-State dependent damage Model in LS-DYNA®

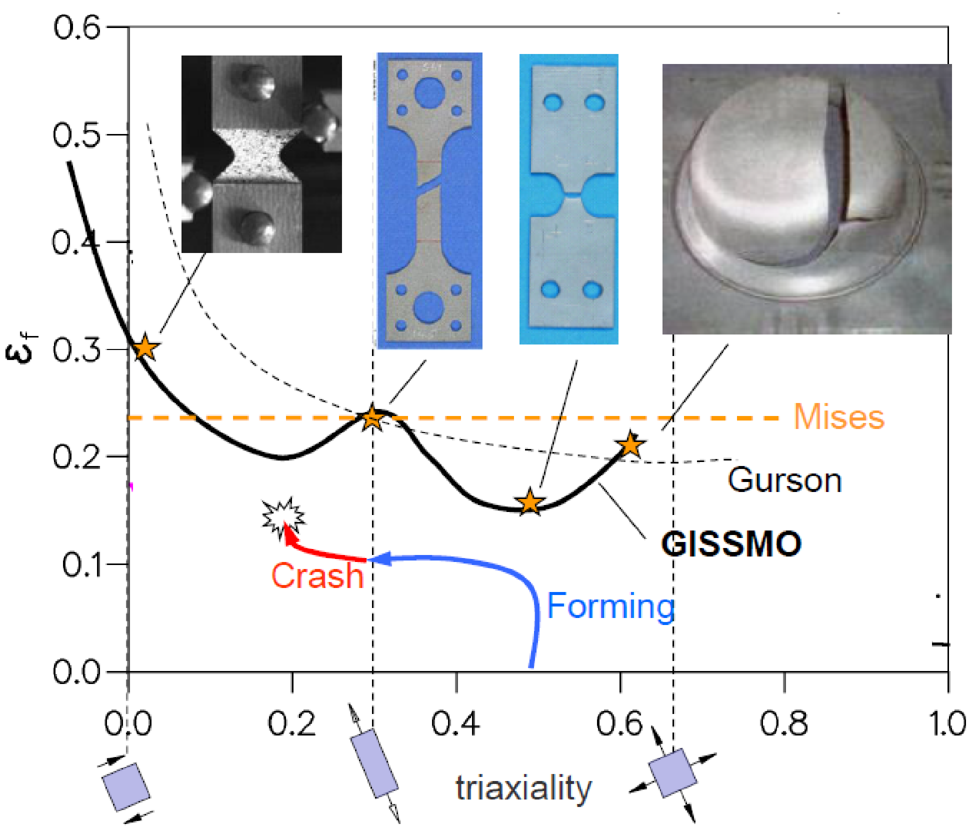
Damage evolution

$$\dot{D}_f = \frac{n}{\varepsilon_f} D_f^{\left(1-\frac{1}{n}\right)} \dot{\varepsilon}_p$$



Damage regularly overestimated for linear damage accumulation!!

Failure curve



Neukamm, Feucht, DuBois & Haufe [2008-2010]

REMARKS & SCOPE OF WORK

TFS for material selection & comparison

- Forming performance
- Uniaxial tension test results mainly
- Represented by: A_f, ε_{1f}, ε_{tf}, $\overline{\varepsilon_f}$

TFS for modeling & simulation

- Forming + crash performance
- Various stress states: shear, tensile, plane strain, & equi-bixial
- Represented by: $\overline{\varepsilon_f}^p$ ($\approx \overline{\varepsilon_f}$ for steels)

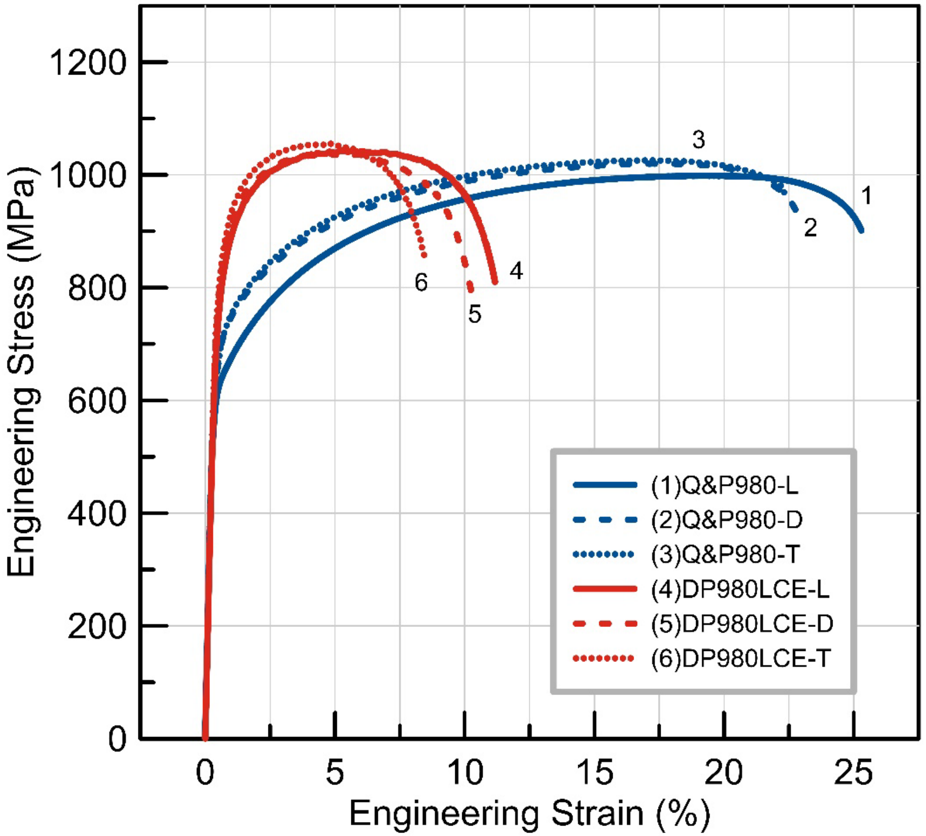
How to measure-derive TFS?

- On uniaxial tensile test samples
- On other stress states samples

TARGET MATERIALS

GI-Q&P980 vs. GI-DP980LCE

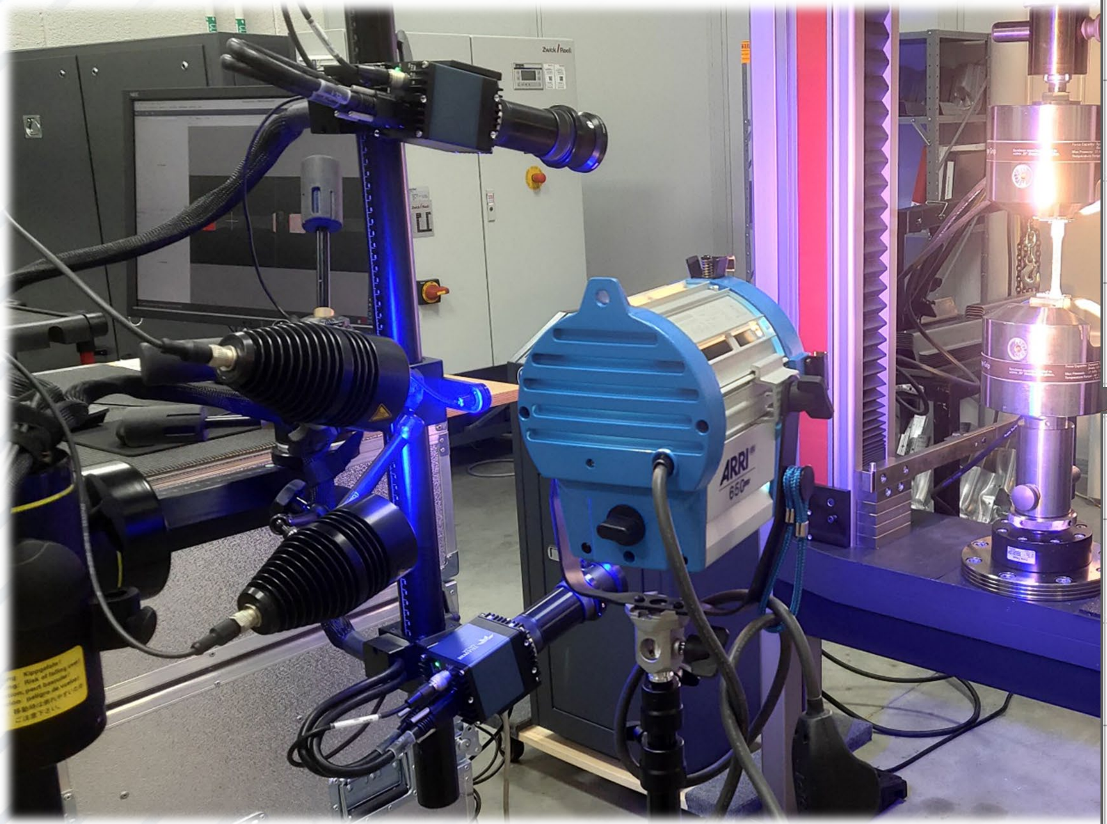
- Nominal thickness: 1.2 mm
- UTS × TE (GPa·%): ~20 vs. ~10 (Gen3 vs. Gen1)
- UE (L/D/T, %): ~19/18/18 vs. ~6/5/4
- TE (L/D/T, %): ~25/23/23 vs. ~11/10/8

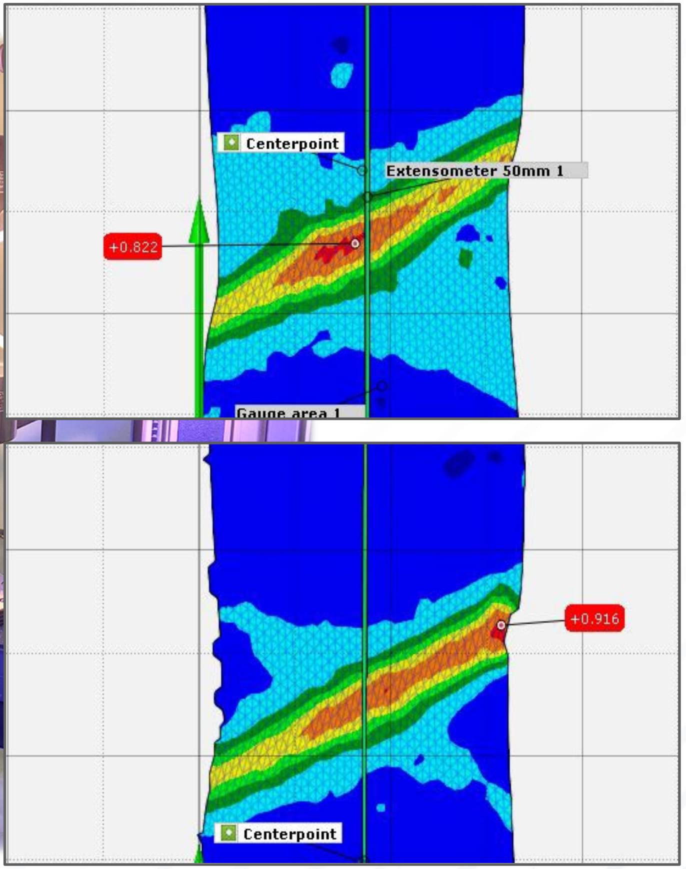


Conclusion 1:

'Formability': Q&P980 > DP980LCE

TFS FROM DIC: OVERVIEW





Tested:

ε_{xx}, ε_{yy}, ε_{xy}

Derived:

ε_1, ε_2, ε_t, $\bar{\varepsilon}_{vM}$

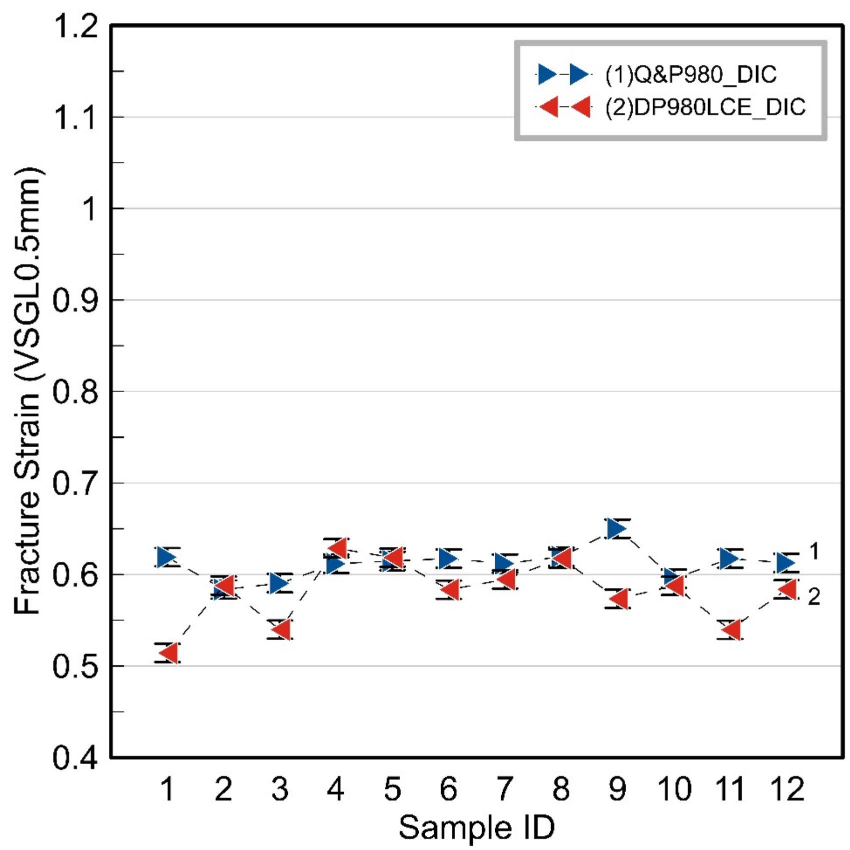
$\varepsilon_1+\varepsilon_2+\varepsilon_t=0$

Volume constancy

$$\bar{\varepsilon}(\mathrm{vM}) \approx \sqrt{\frac{2}{3}({\varepsilon_1}^2 + {\varepsilon_2}^2 + {\varepsilon_t}^2)}$$

TFS FROM DIC: RESULTS

12 longitudinal ASTM-E8 tensile samples of each grade were tested at 0.001/s at room temperature



Conclusion 2:

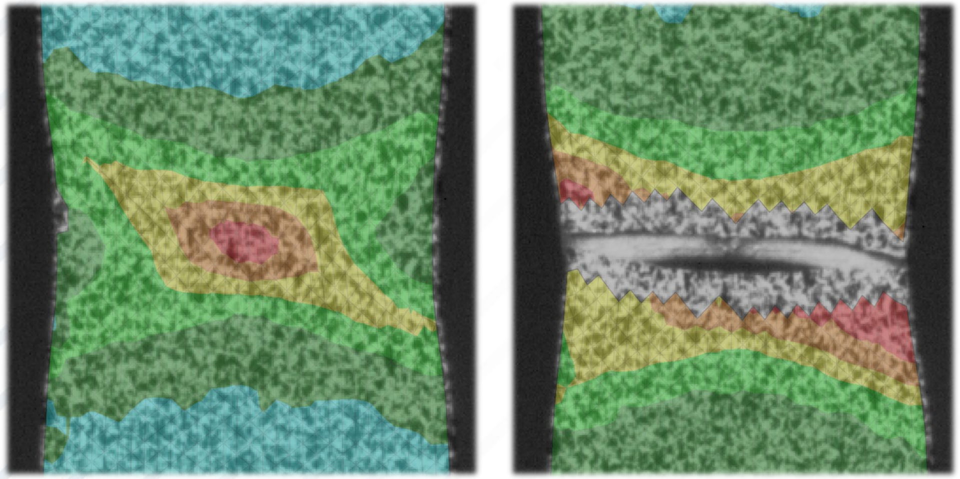
'Formability': Q&P980 ≈ DP980LCE

TFS FROM DIC: EFFECTS OF FRAME RATE

The DIC-based TFS result is based on the last image before fracture

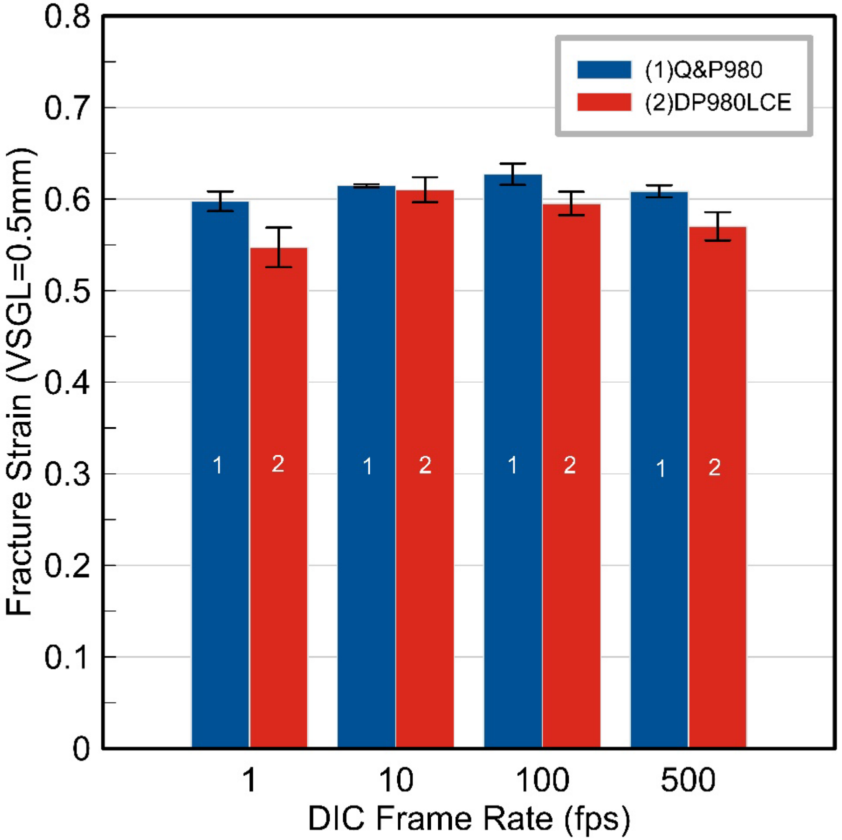
DIC frame rates: Sample 1-3, 1 Hz; Sample 4-6, 10 Hz; Sample 7-9, 100 Hz; Sample 10-12, 500 Hz

*Some steels exhibit pronounced sensitivity

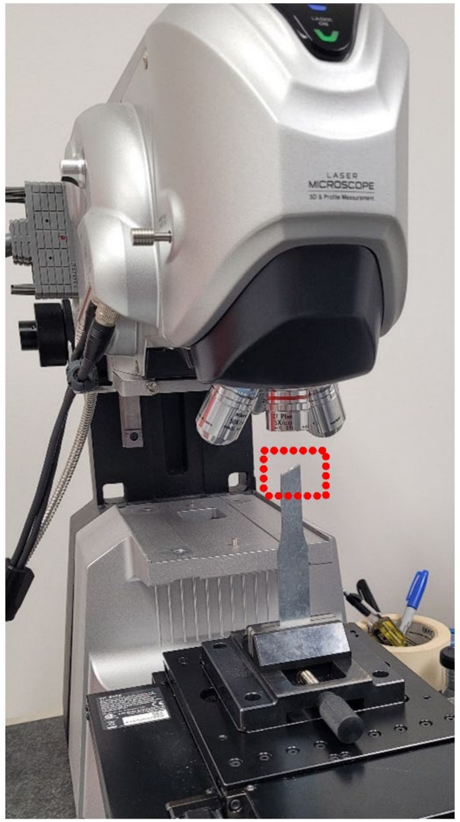


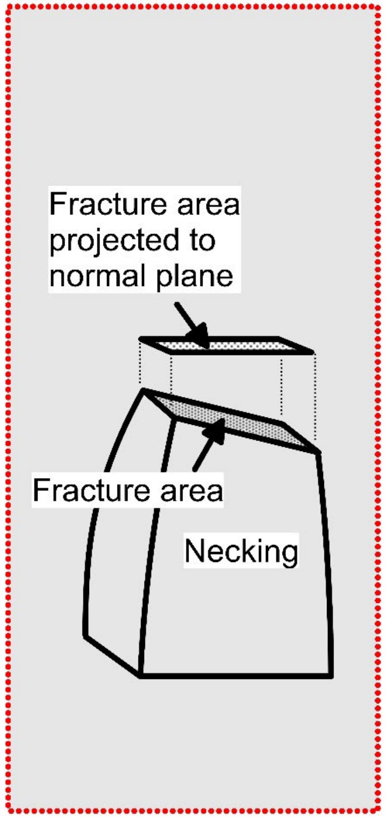
Last image before fracture

First image after fracture



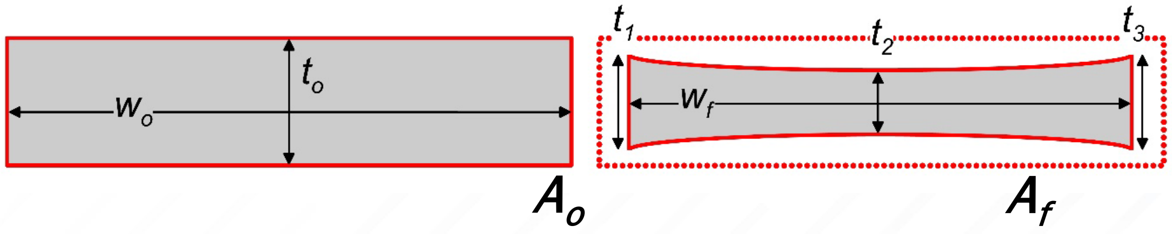
TFS FROM FRACTURE AREA (FA) OPTICAL



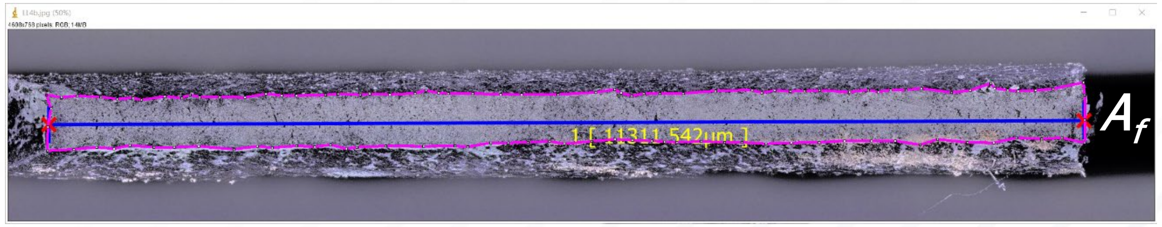


- Parabolic approximation (Optical (P), ASTM E8):

$$t_f = \frac{1}{6}(t_1 + 4t_2 + t_3)$$



- Area of polygon fit (Optical (A)):

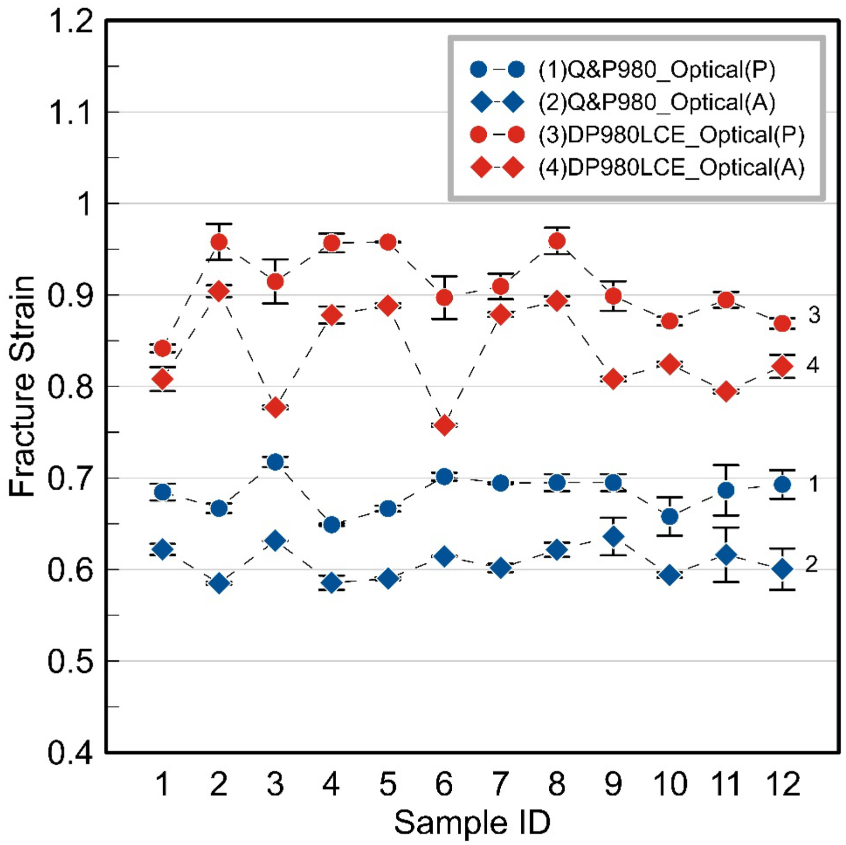


$$\bar{\varepsilon}(\mathrm{vM}) \approx \varepsilon_{1f} = \int_{l_o}^{l_f} \frac{dl}{l} = \ln\left(\frac{l_f}{l_o}\right) = \ln\left(\frac{A_o}{A_f}\right) = \ln\left(\frac{w_o t_o}{w_f t_f}\right)$$

Volume constancy

TFS FROM FA-OPTICAL: RESULTS

Without parabolic approximation, the Optical (A) results are comparatively more accurate

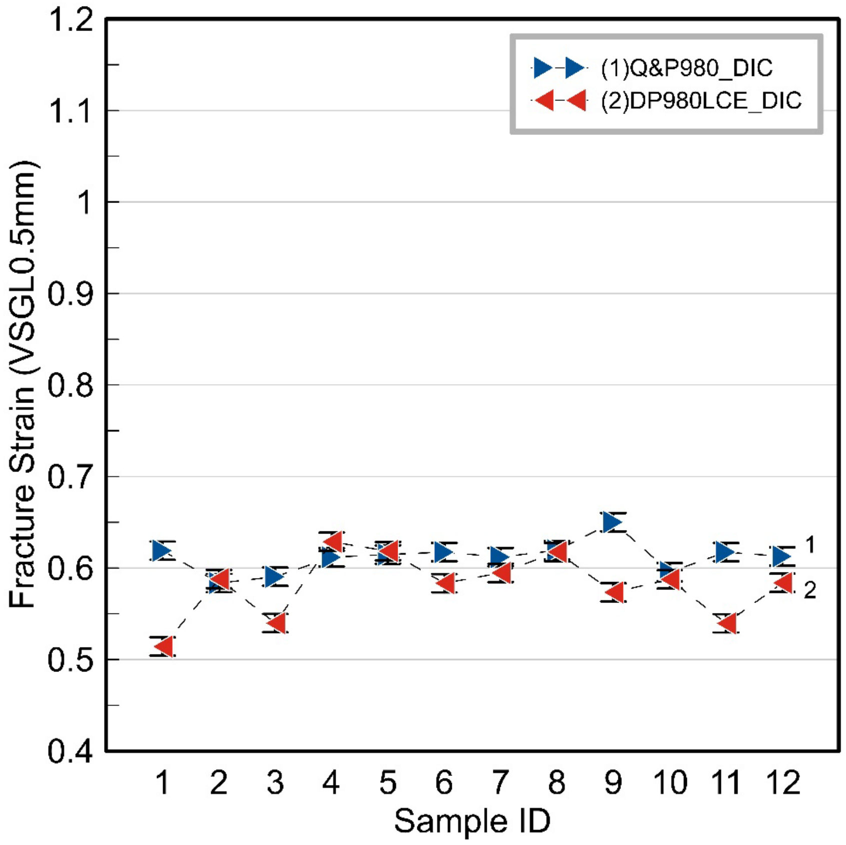


Conclusion 3:

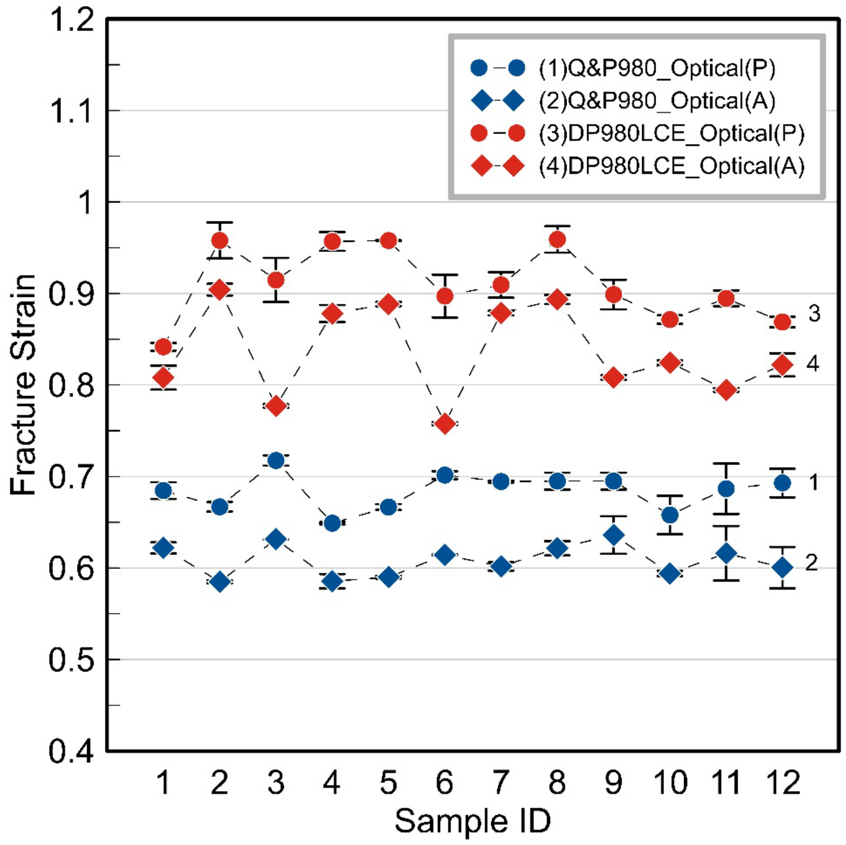
'Formability': Q&P980 < DP980LCE

DIC VS. FA-OPTICAL RESULTS

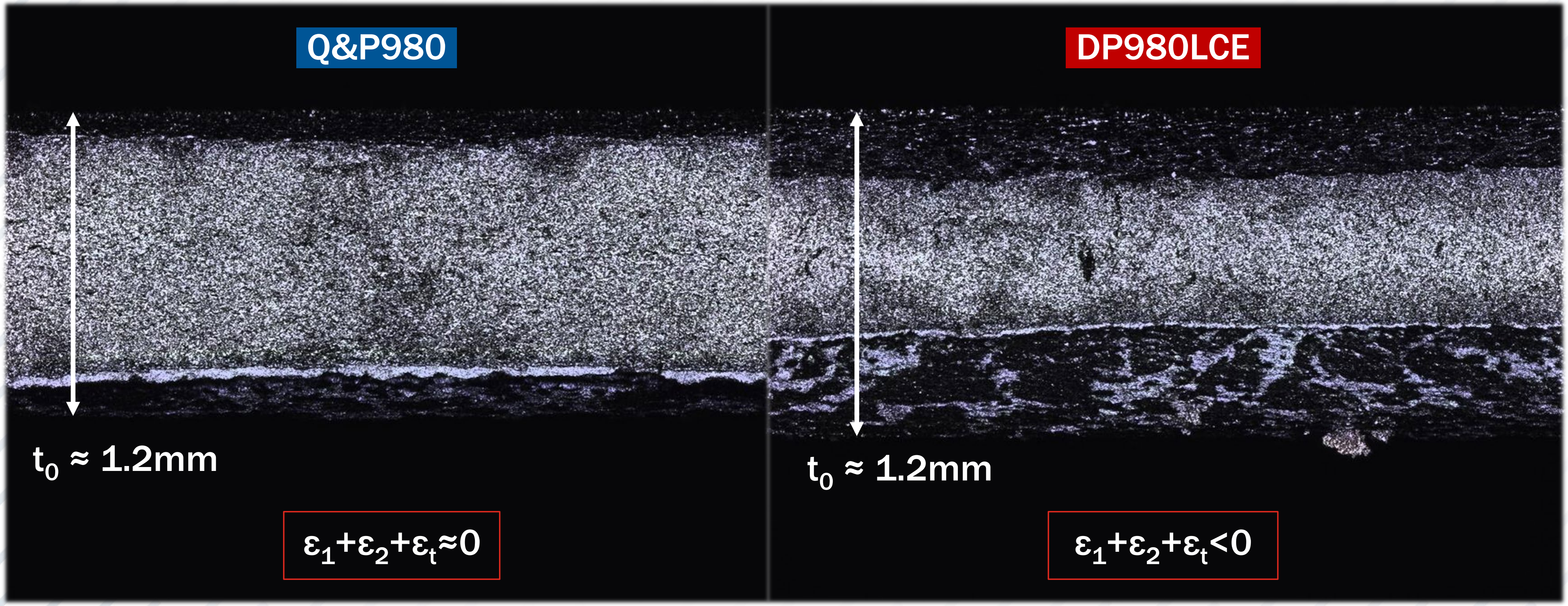
DIC Results



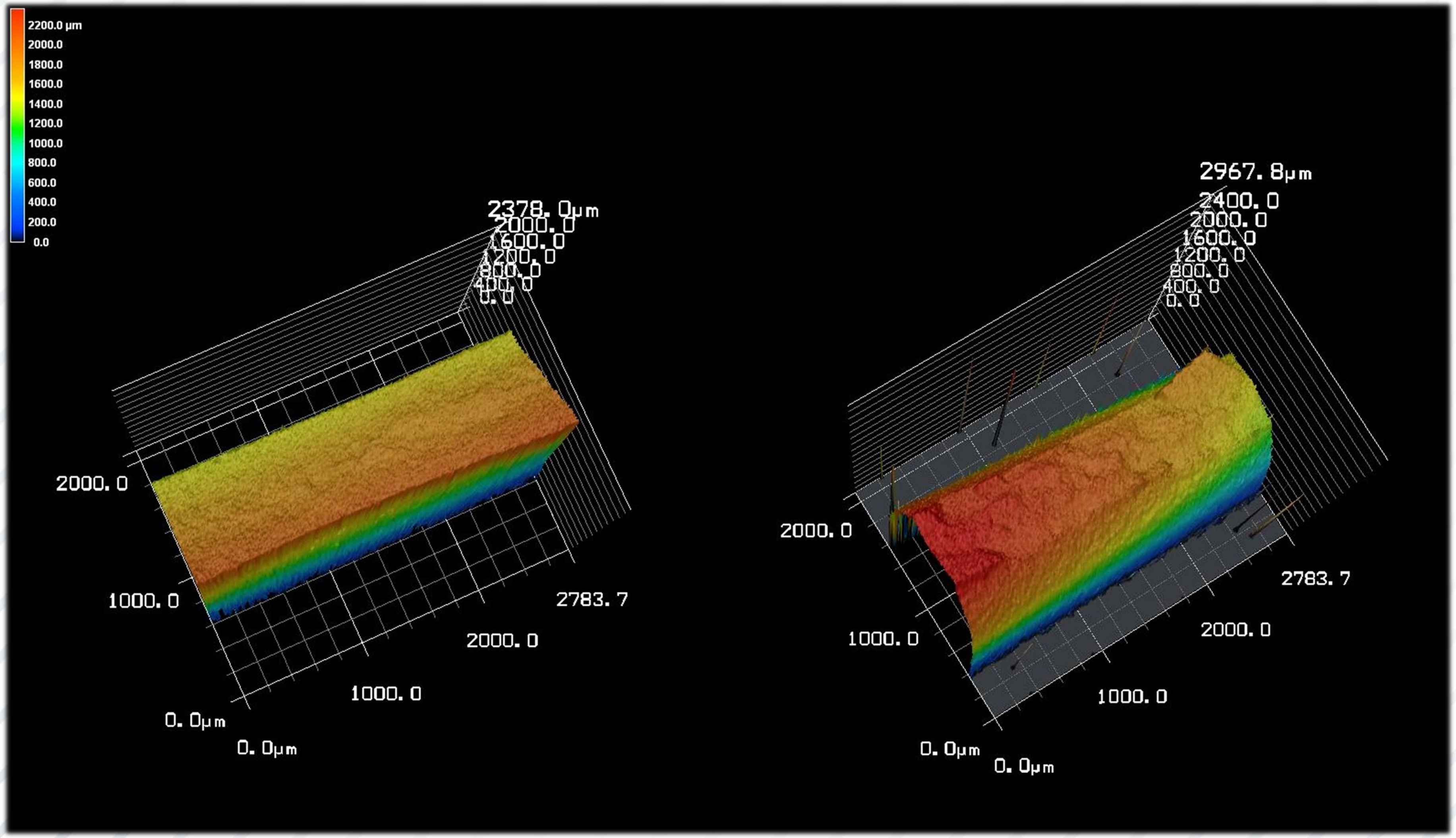
FA-Optical Results



DISCREPANCY ANALYSIS: THINNING

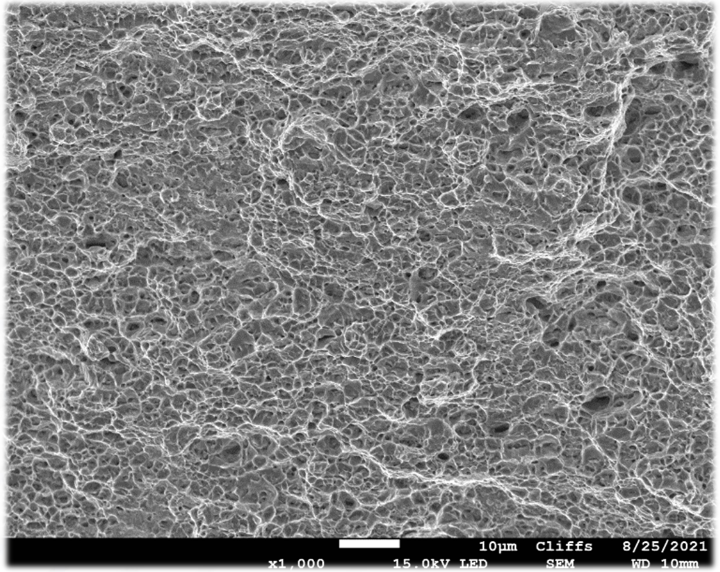


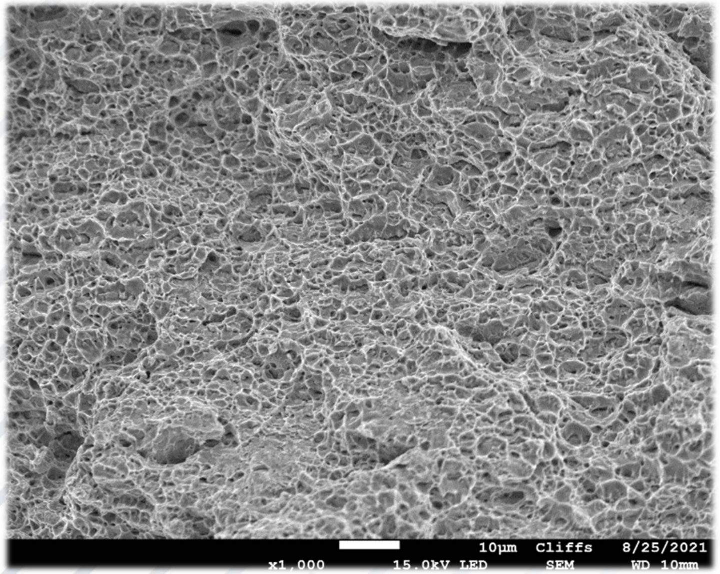
DISCREPANCY ANALYSIS: FRAC. SURFACE



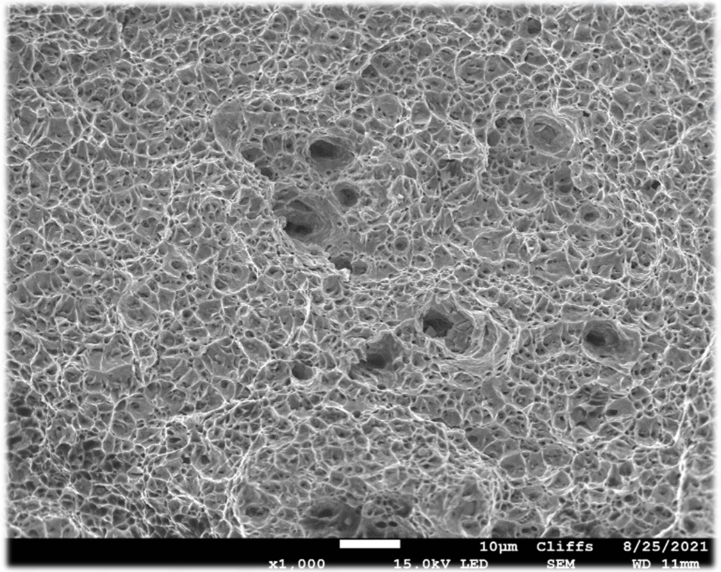
DISCREPANCY ANALYSIS: VOIDS

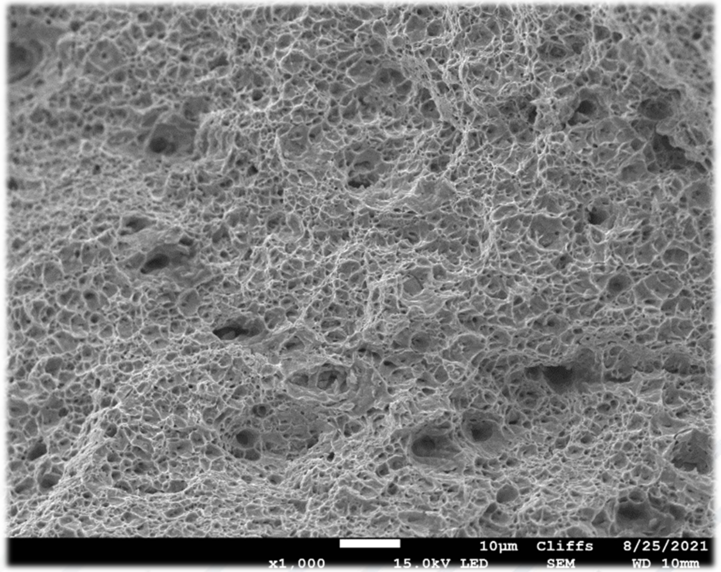
Q&P980





DP980LCE





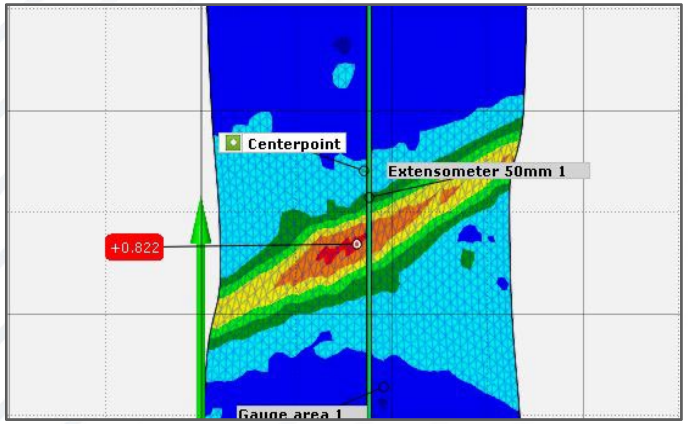
DISCREPANCY ANALYSIS: REMARKS

- The volume constancy assumption is mainly responsible for the discrepancy and deviation.
- Either the DIC method or the FA-optical measurement is based on and affected by the volume constancy assumption. Yet the impact on the FA-optical results is comparatively less.
- The deviation induced by the volume constancy assumption is material-dependent.
- An alternative method should avoid such an assumption.

ALTERNATIVE: HYBRID METHOD

Use the DIC results (ε_1, ε_2) + measured thickness strain (ε_t) to derive the effective strain ($\bar{\varepsilon}$) at fracture → avoid the volume constancy assumption

*Limitation: synchronization deviation



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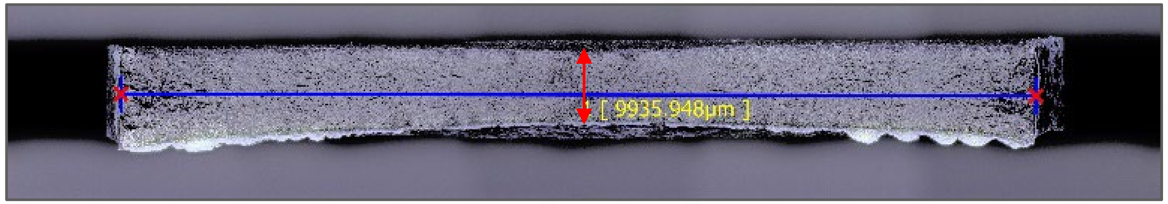
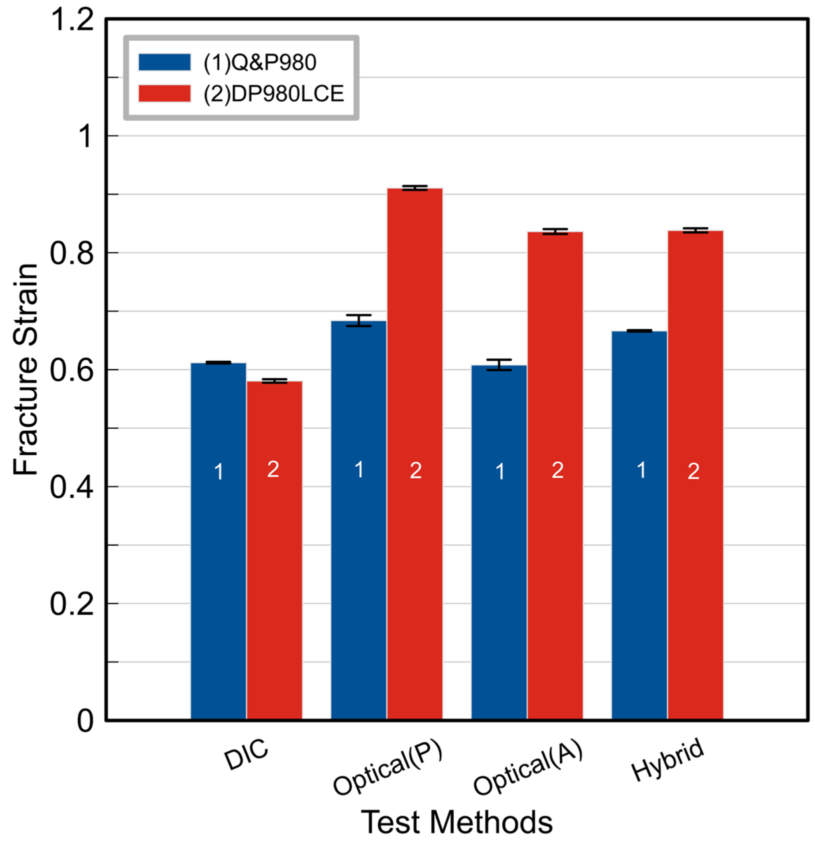


$$\bar{\varepsilon}(\text{vM}) \approx \sqrt{\frac{2}{3}({\varepsilon_1}^2 + {\varepsilon_2}^2 + {\varepsilon_t}^2)}$$

DIC VS. FA-OPTICAL VS. HYBRID

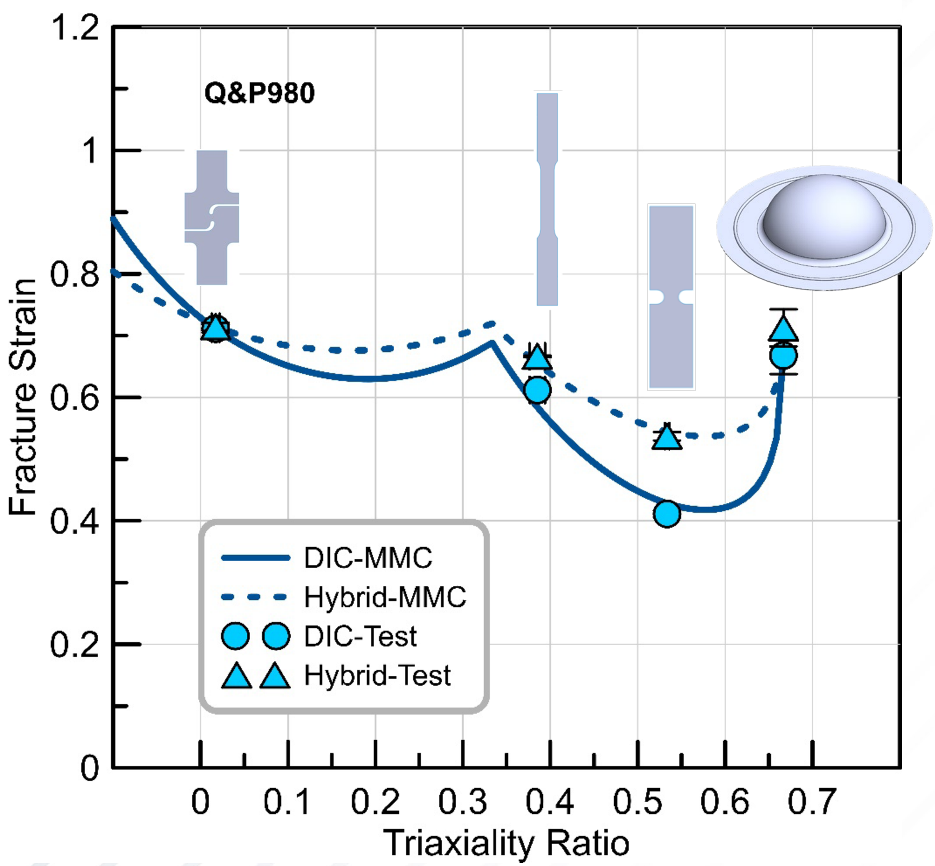


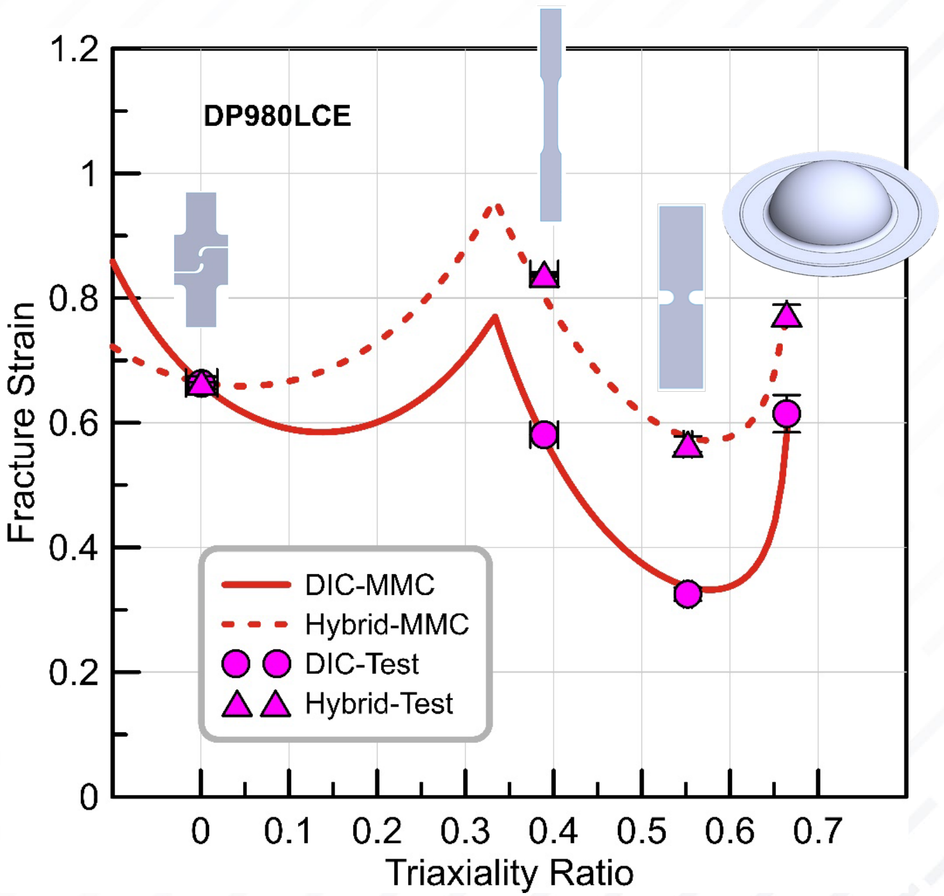
	DIC	FA-Optical	Hybrid
Complexity	Complex	Simple	Most complex
Accuracy	Sometimes largely deviated	Some deviations	Most accurate
Applicability	All stress states	Mainly tensile	All stress states

FA-Optical: Recommended for mat. selection & comparison

Hybrid: Recommended for modeling & simulation

DIC VS. HYBRID: FRACTURE LOCI





CONCLUSIONS

- TFS (fracture resistance) ≠ UE/FLC (necking resistance)
- A material can exhibit high TFS and low UE/FLC, or vice versa.
- TFS measurement-derivation is not straightforward.
- The TFS from the default DIC method is questionable due to the volume constancy assumption and may underestimate the local formability of some materials.
- The TFS from the fracture area optical measurement is good enough for material selection & comparison. The results can already reveal the goodness of the local formability, despite some inaccuracy.
- As an alternative, a hybrid method is proposed mainly for fracture modeling and simulation, though the synchronization issue still affects the accuracy.

FOR MORE INFORMATION

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