GREAT DESIGNS IN STEEL

FORMABILITY AND FRACTURE VALIDATION OF 3RD GEN STEELS

A collaborative project between Honda R&D Americas, AISI Automotive Program, Bowman Precision Tooling, and the University of Waterloo

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PROJECT STRUCTURE

Three 3rd Gen steels (980 & 1180 MPa nominal strength) were supplied to AISI Sample Bank

↓

Material identification removed and sent to UW for formability and fracture characterization (no microstructural characterization)

↓

Design representative B-pillar for mid-sized SUV, perform forming trials, and impact test

↓

Full-scale evaluation of CAE capabilities of 3rd Gen AHSS from Forming-to-Fracture

PROJECT GOALS

Characterize mechanical properties of 3rd Gen steels provided by AISI

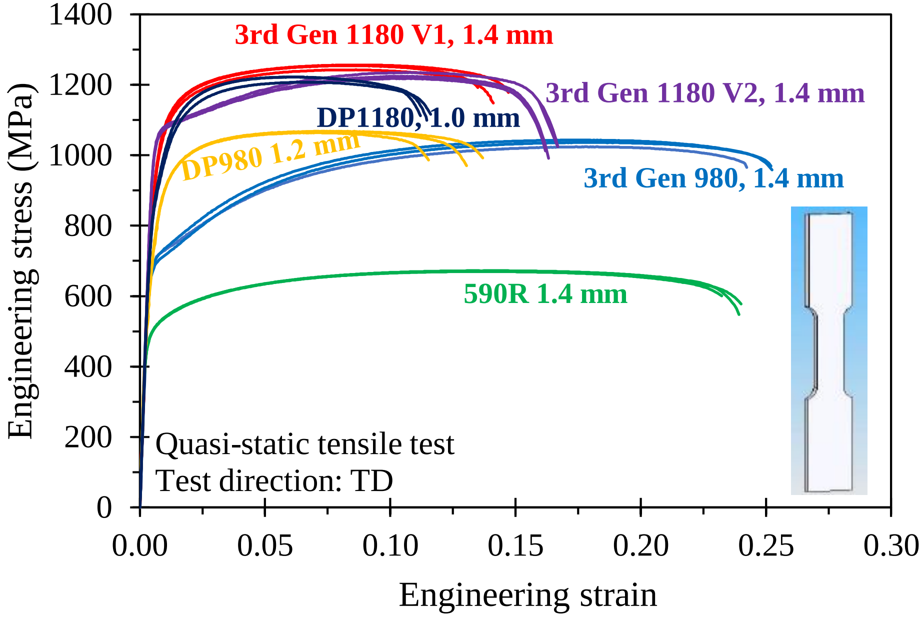
Apply optimized fracture testing methodology established for AHSS (GDIS 2017 & GDIS 2018) to 3rd Gen AHSS (GDIS 2019)

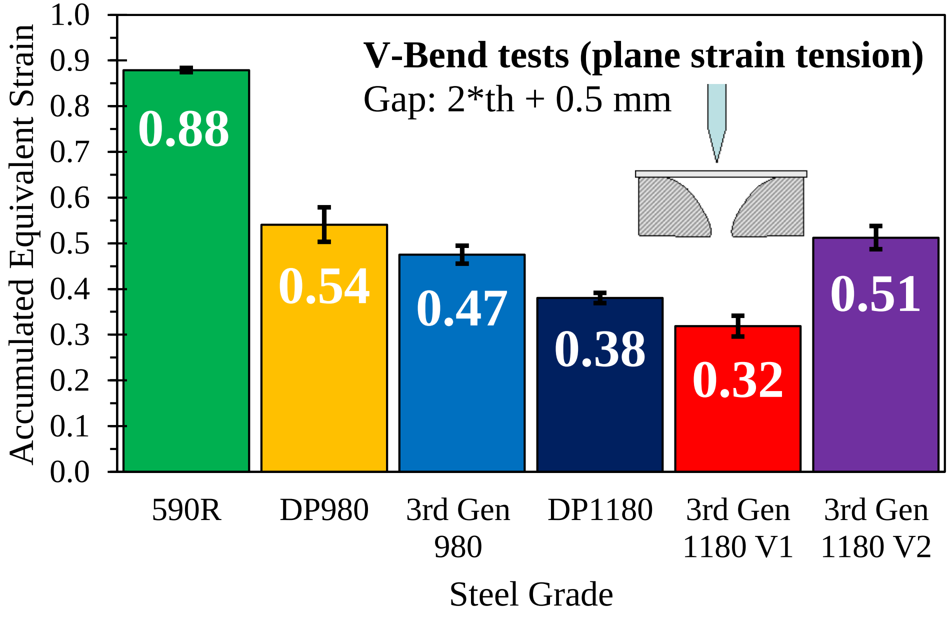
Formability characterization and prediction of 3rd Gen AHSS to integrate into fracture CAE toolkit from forming-to-crash

Design forming process of full-size B-pillar for mid-size SUV using CAE toolkit with Bowman Precision Tooling and Honda R&D Americas

Perform dynamic B-pillar impact tests to evaluate CAE toolkit and methodology to design 3rd Gen steel components (GDIS 2022)

MATERIAL PERFORMANCE





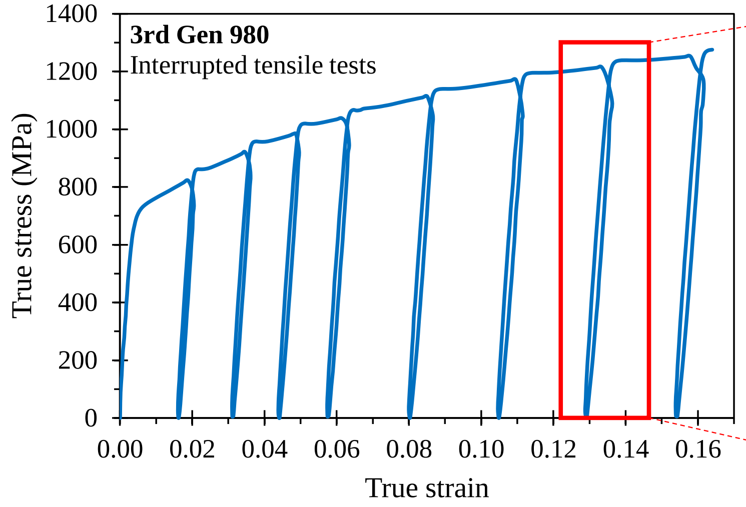
Grade	Nominal sheet thickness (mm)	Yield strength (MPa)	Ultimate Tensile Strength (MPa)	Yield-to-UTS ratio	Uniform Elongation UE (%)	Total Elongation TE (%)
590R	1.4	490 (±2)	671 (±1)	0.73	19.9 (±0.3)	23.7 (±0.4)
DP980	1.2	735 (±2)	1065 (±3)	0.69	7.8 (±0.2)	13.7 (±0.5)
3rd Gen 980	1.4	681 (±8)	1034 (±10)	0.66	18 (±0.5)	24.9 (±0.6)
DP1180	1.0	843 (±0)	1216 (±8)	0.69	6.5 (±0.4)	11.5 (±0.2)
3rd Gen 1180 V1	1.4	950 (±12)	1251 (±8)	0.76	8.4 (±0.2)	14.1 (±0.6)
3rd Gen 1180 V2	1.4	1043 (±4)	1225 (±8)	0.85	10.7 (±0.4)	16.4 (±0.3)

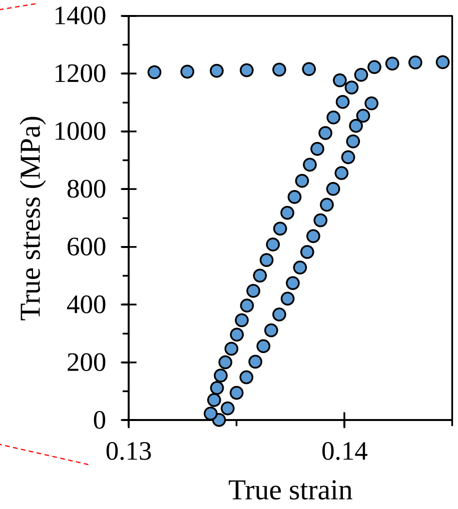
DP1180 retrieved from Numisheet 2022 Benchmark: https://www.tms.org/portal/MEETINGS___EVENTS/TMS_Meetings___Events/Upcoming_TMS_Meetings/NUMISHEET2021/benchmarkTests/portal/Meetings___Events/2021/NUMISHEET2021/

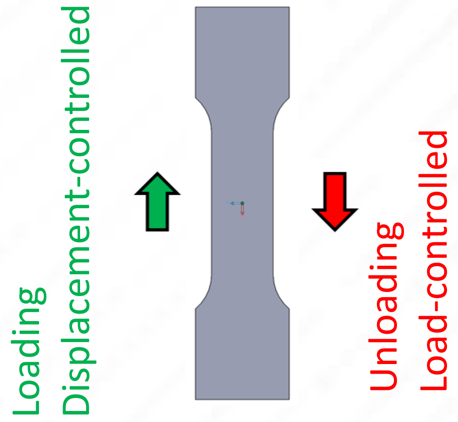
Constitutive Characterization

CHARACTERIZATION OF CHORD MODULUS

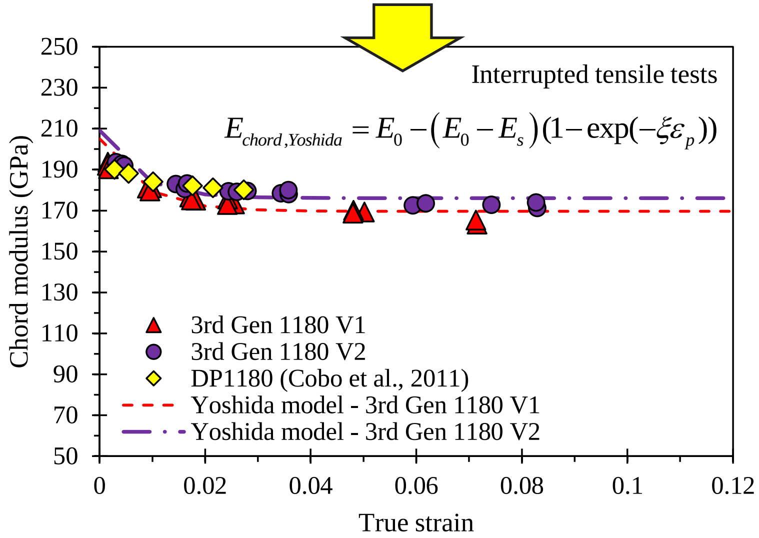
Chord modulus can be critical for springback: Perform loading-unloading



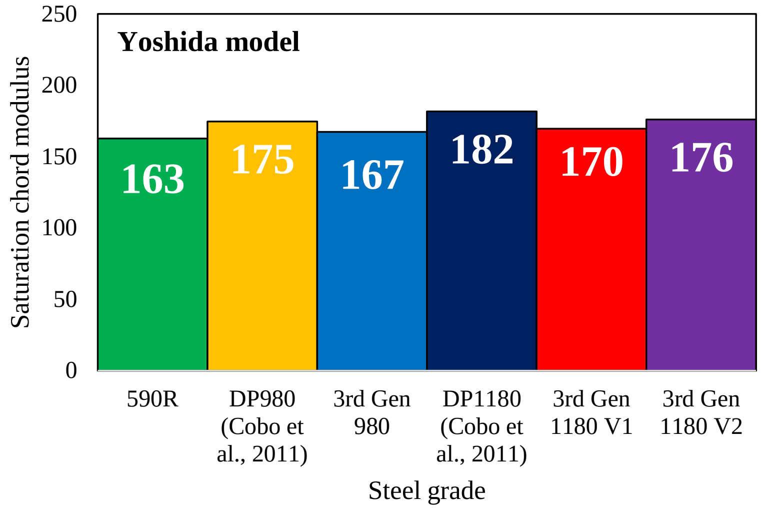




JIS No. 5 geometry



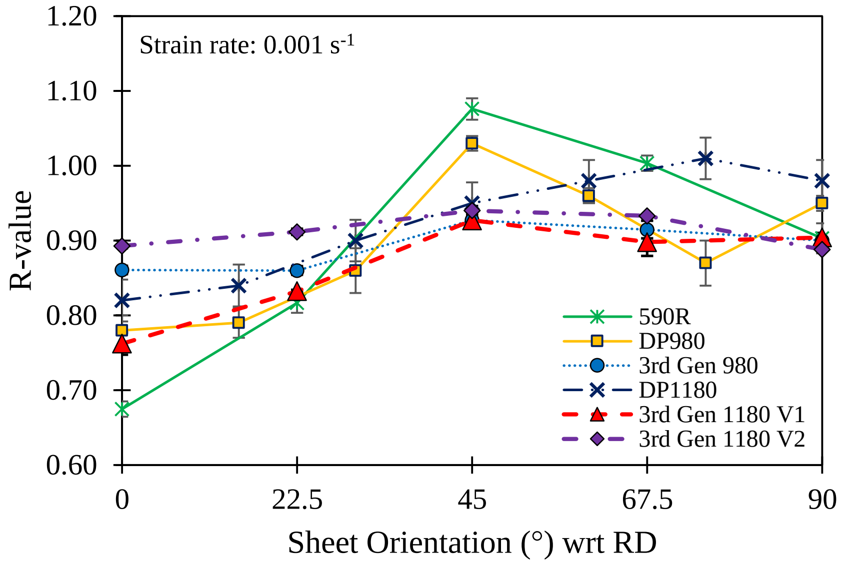
Saturation chord modulus of tested 3rd Gen steels similar to DP literature data

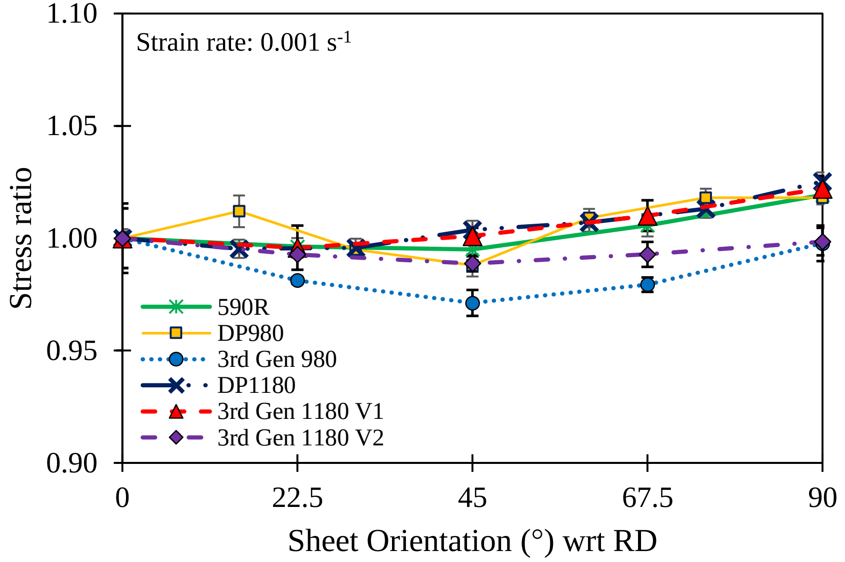


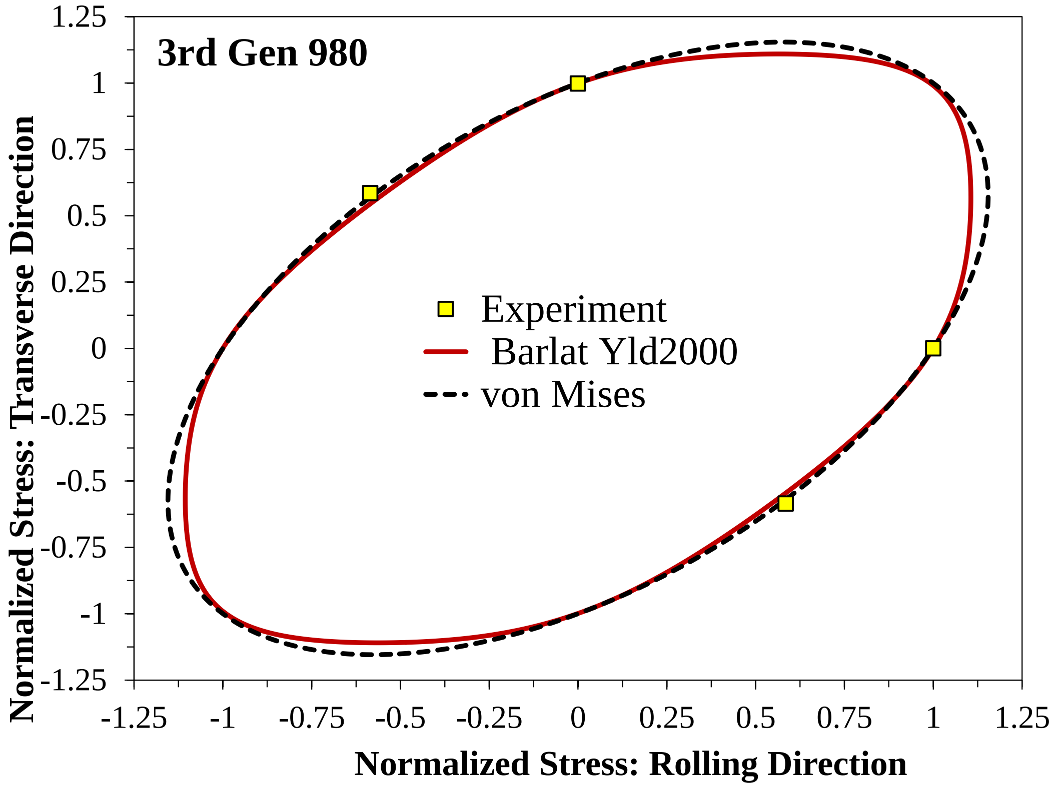
Ref. 1 and 2

MATERIAL ANISOTROPY

GDIS







Anisotropy of studied 3rd Gen steels was mild and comparable to DP steels

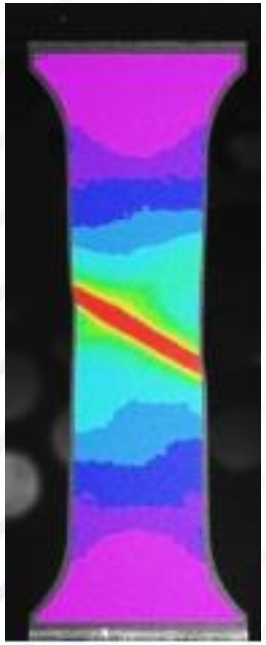
Assumption of von Mises can be reasonable approximation depending on CAE objectives

Ref. 3

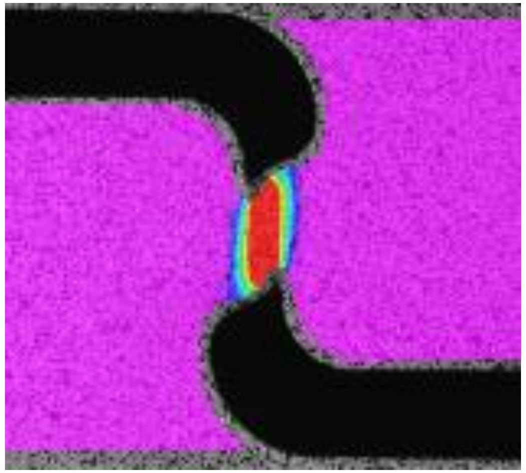
CALIBRATION HARDENING MODEL

Isotropic hardening response obtained using tensile & shear tests

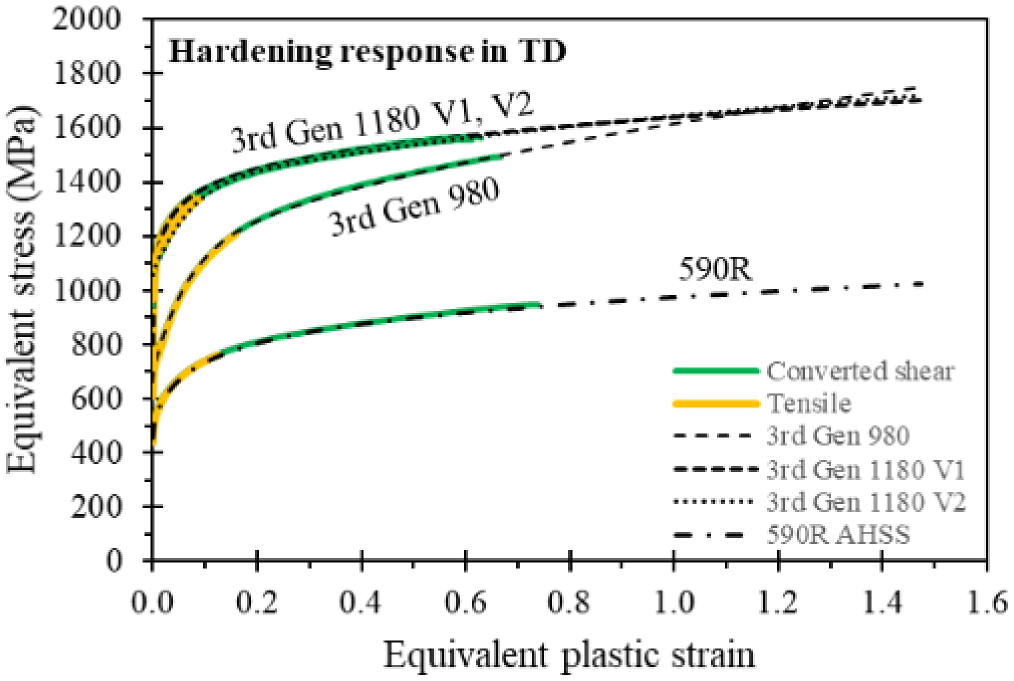
Methodology in Rahmaan *et al.* (2017) and refined in Noder & Butcher (2019)



Tensile Test until UTS



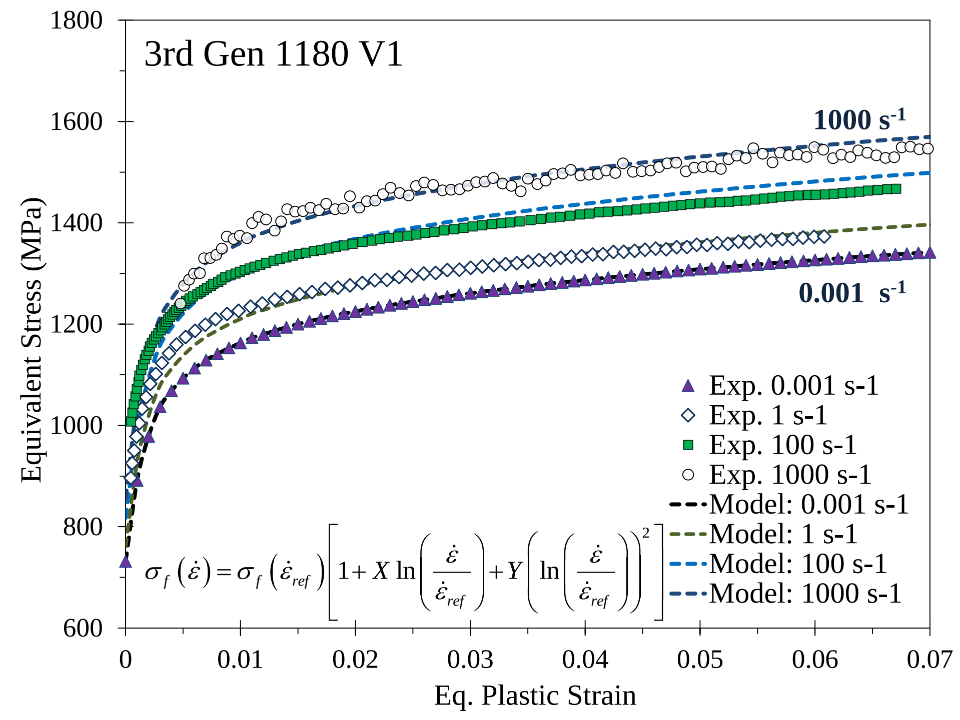
Simple Shear After Tensile UTS

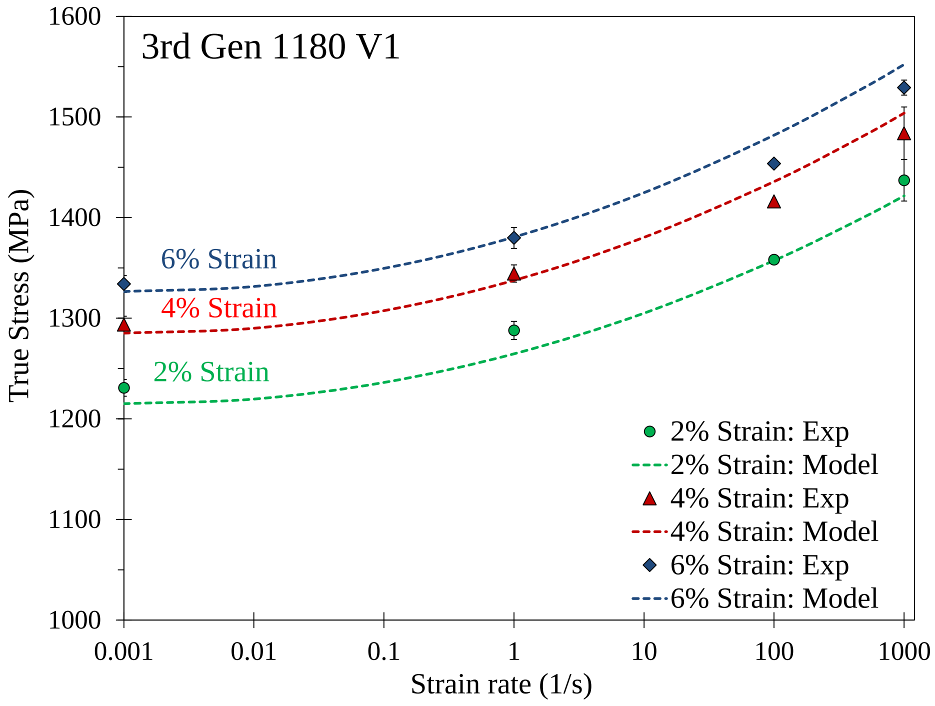


Ref. 4 and 5

RATE SENSITIVITY

Intermediate and high-rate tensile tests at ~ 1, 100, and 1000 s^{-1}



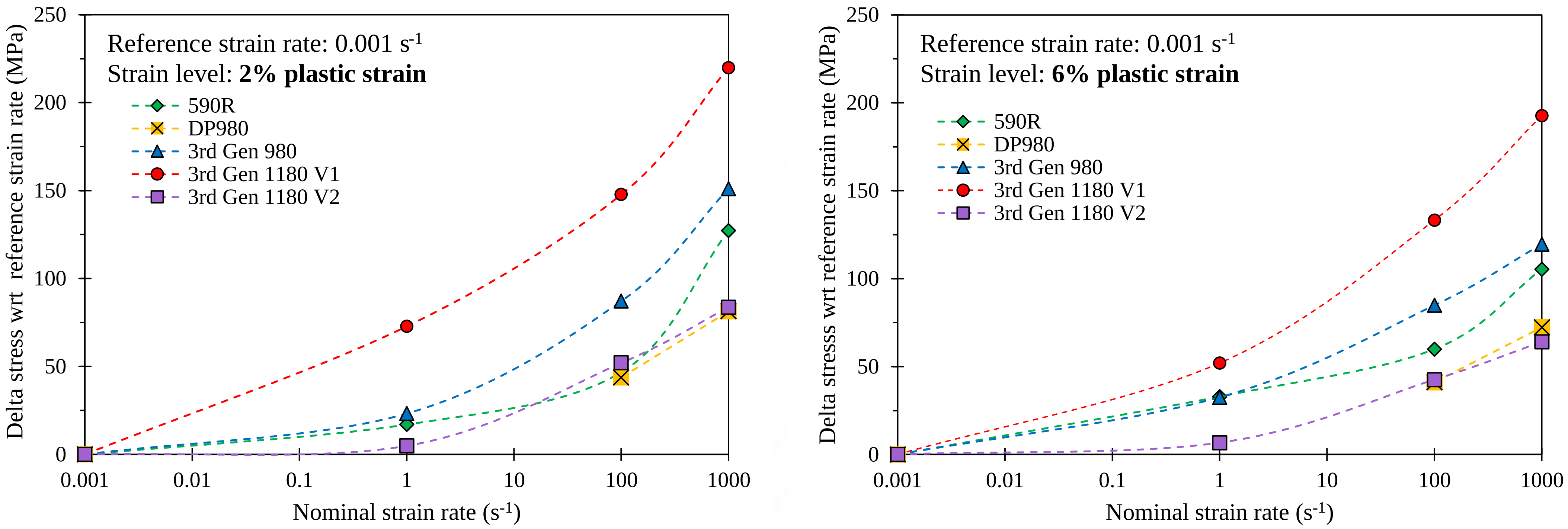


Modified Johnson Cook hardening model captures strain rate sensitivity well

COMPARISON OF STRAIN RATE EFFECTS

Strain rate sensitivity of 3rd Gen 1180 V2 was mild compared to 3rd Gen 1180 V1

Rate sensitivity of V2 was about 3x lower than V1

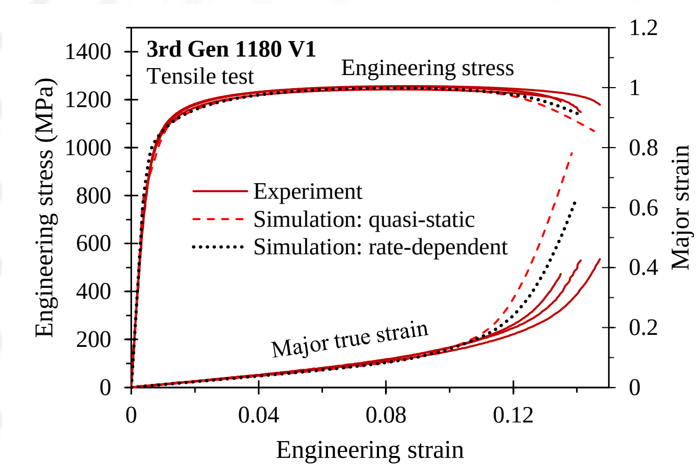


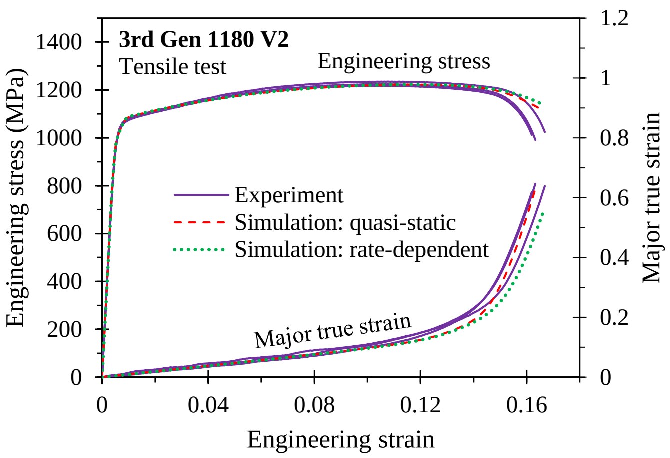
Rate sensitivity of 3rd Gen 980 was slightly higher than DP980

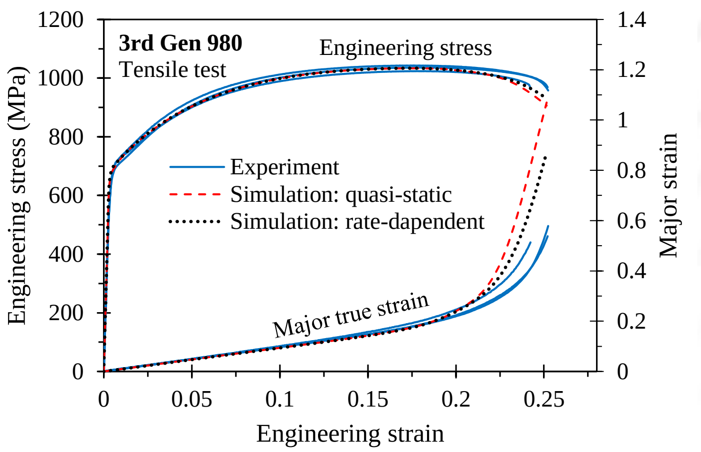
Rate sensitivity beneficial for formability but increases press tonnage

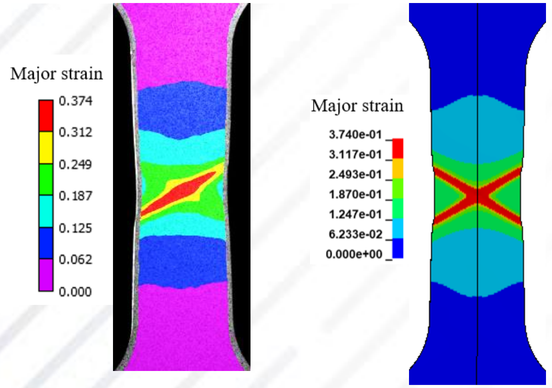
EVALUATION HARDENING MODEL

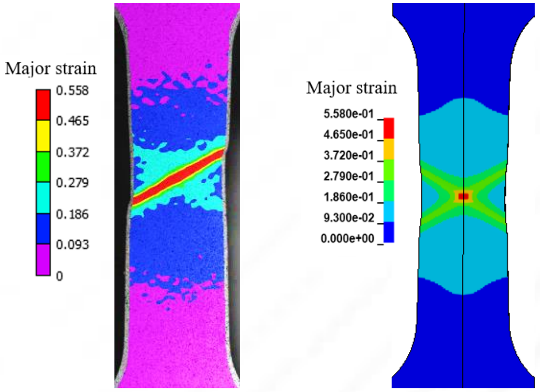
Solid tensile simulations using fully-integrated EL, 0.3 mm mesh size in LS-DYNA

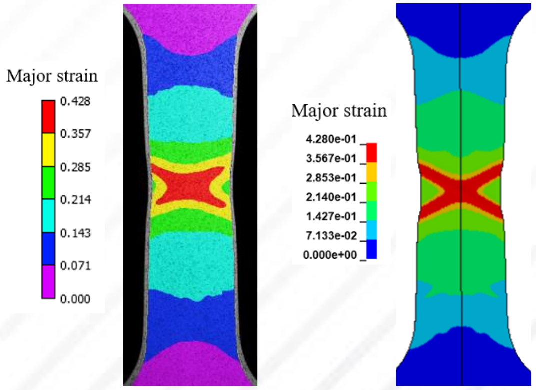












Global stress-strain response in very good agreement without inverse FEA

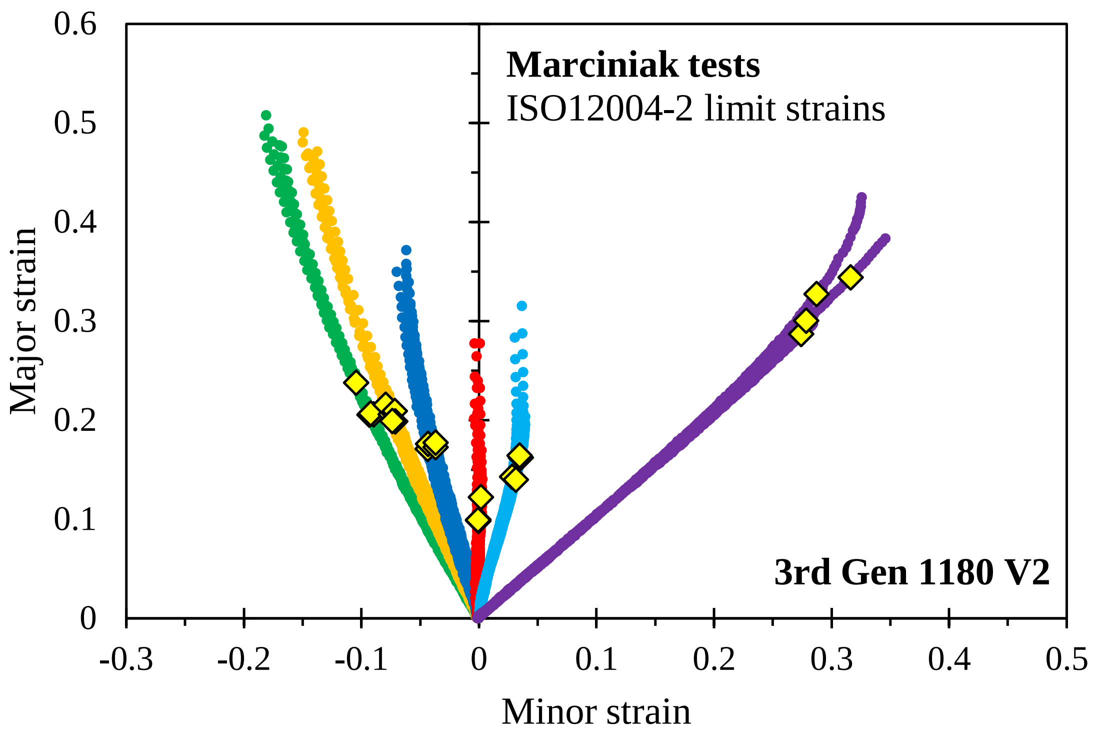
Local strains slightly deviate for 3rd Gen 1180 V1 but localization is also different

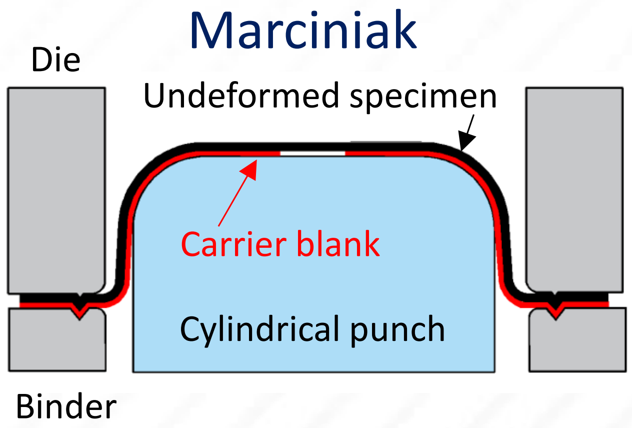
Formability Characterization and Prediction

MARCINIAK TESTS FOR FLC CHARACTERIZATION

Marciniak tests for in-plane stretching under plane stress

Consistent with physical framework of selected analytical FLC model



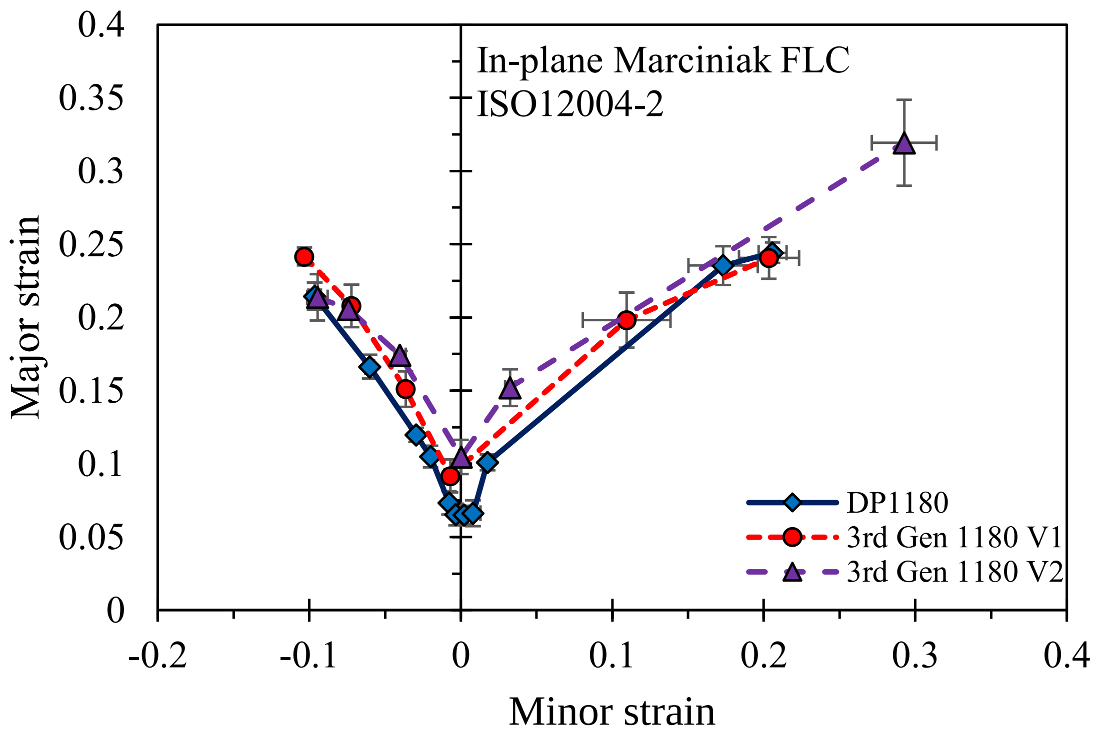


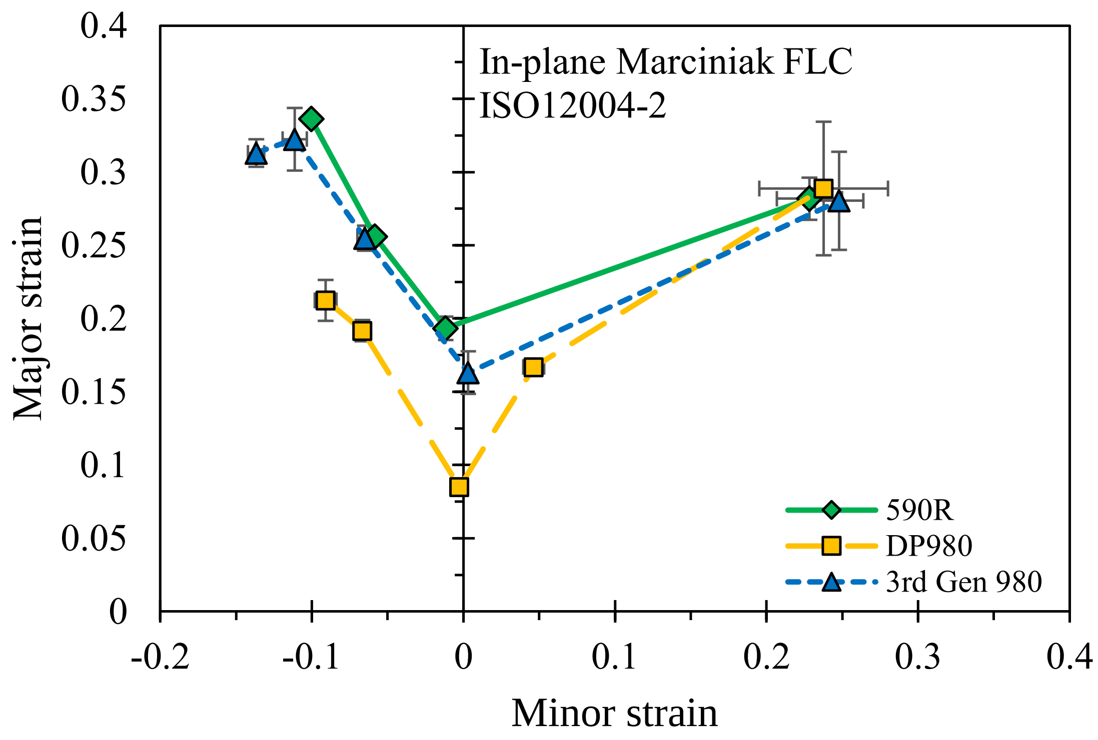
Approximately linear strain path and plane stress in Marciniak tests

IN-PLANE FORMING LIMIT STRAINS

Global formability similar for 1180 MPa strength steels

→ *Slightly higher FLC_0 and biaxial limit strain for 3rd Gen 1180 V2*





Limit strains of 3rd Gen 980 superior to DP980, 3rd Gen 980 FLC comparable to 590R

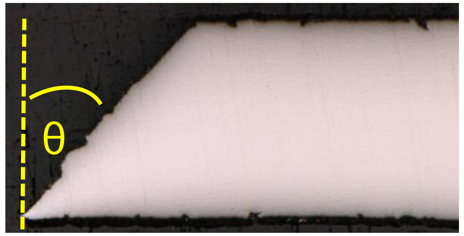
ANALYTICAL FLC PREDICTION

Stretch side of the FLC: Bressan-Williams (BW) through-thickness shear model

Necking along zero-extension angle through the sheet thickness

$$\cos(2\theta) = -\frac{\rho}{2+\rho}, \quad \rho = \frac{d\varepsilon_2}{d\varepsilon_1}$$

$$\tau_{cr} = \frac{\sigma_1}{2}\sin(2\theta) = \sigma_1 \frac{\sqrt{1+\rho}}{(2+\rho)}$$



Draw side of the FLC: Extension (BWx model)

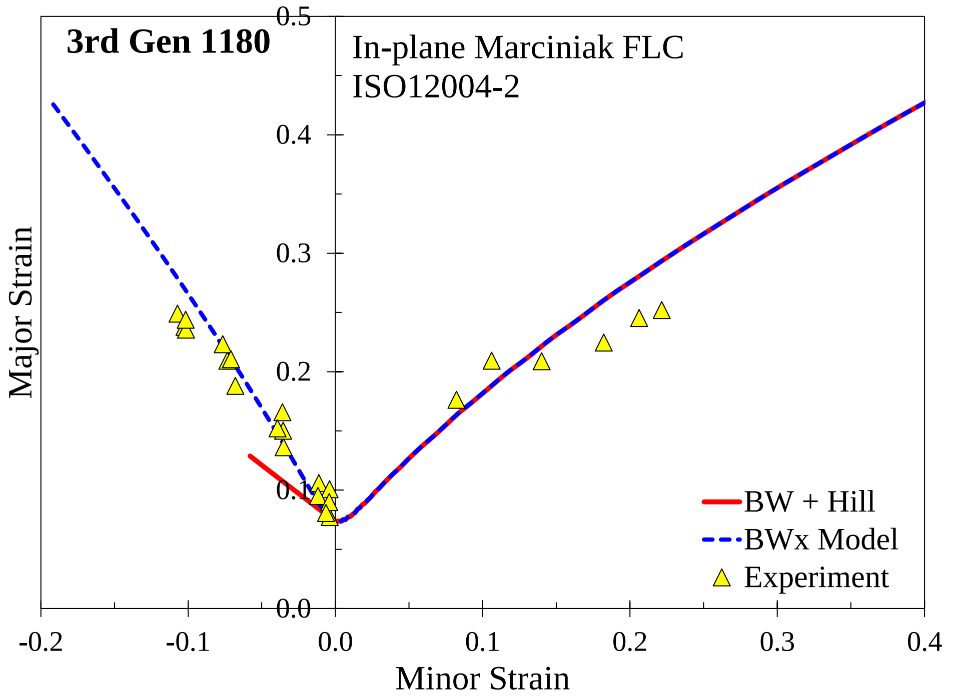
Necking when critical in-plane shear stress reached (Hance & Huang, 2018)

$$\tau_{cr}^{BWx} = \frac{\sigma_1}{2}$$

Critical shear stress is calibration parameter

→ Used Swift model for diffuse necking in plane strain

→ BWx model is simple and deterministic

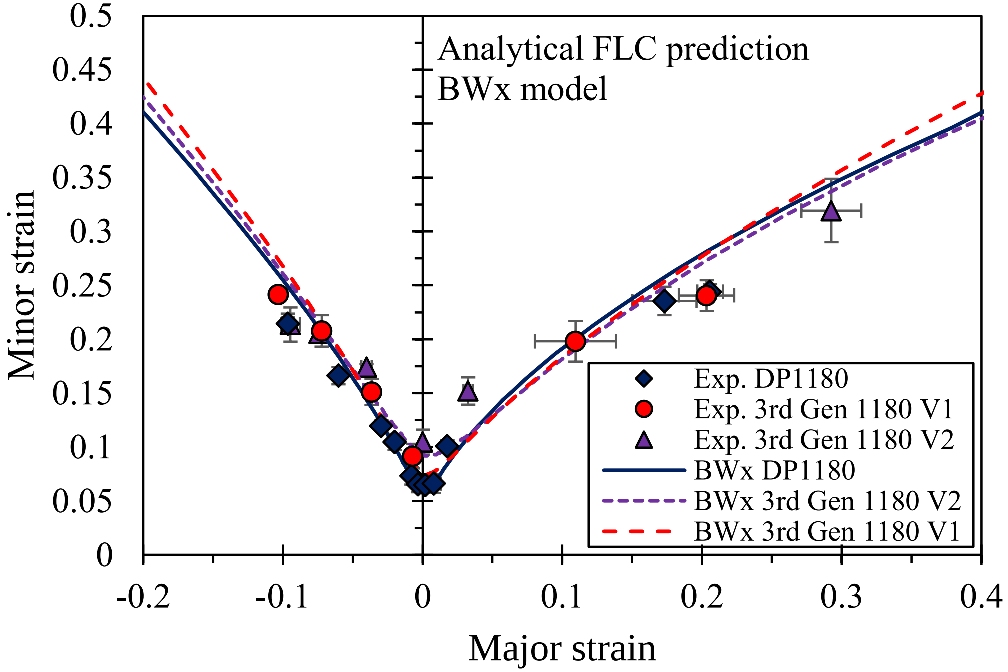


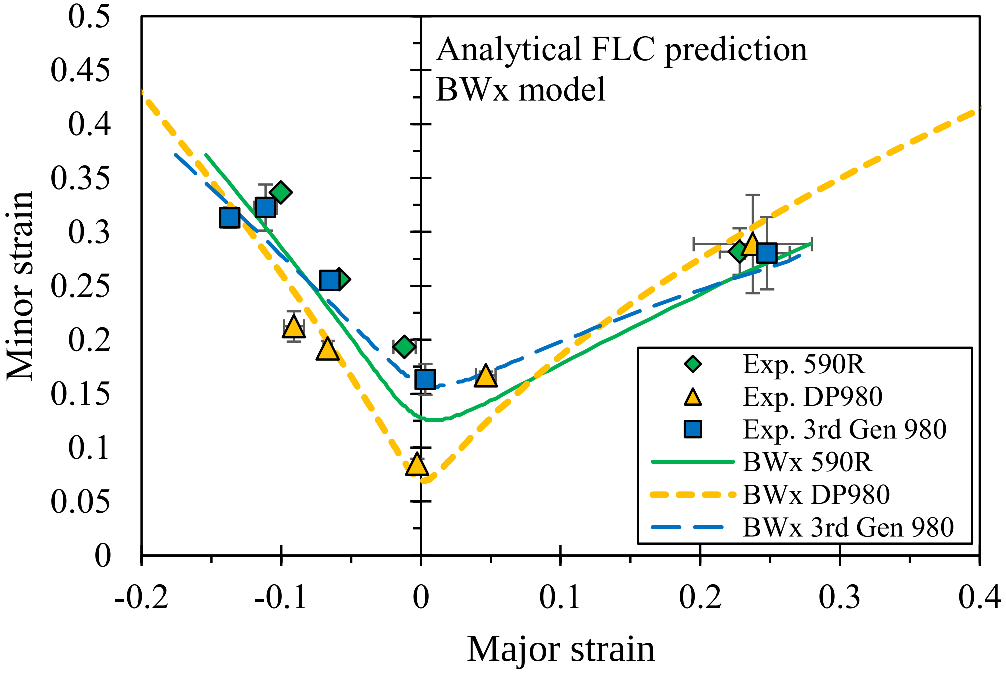
BWx model on draw side provides superior correlation than conventional Hill (1952) model

Ref. 6, 7, 8, and 9

ANALYTICAL FLC PREDICTION

Simple and deterministic BWx model can accurately predict in-plane forming limits for studied DP and 3rd Gen steels

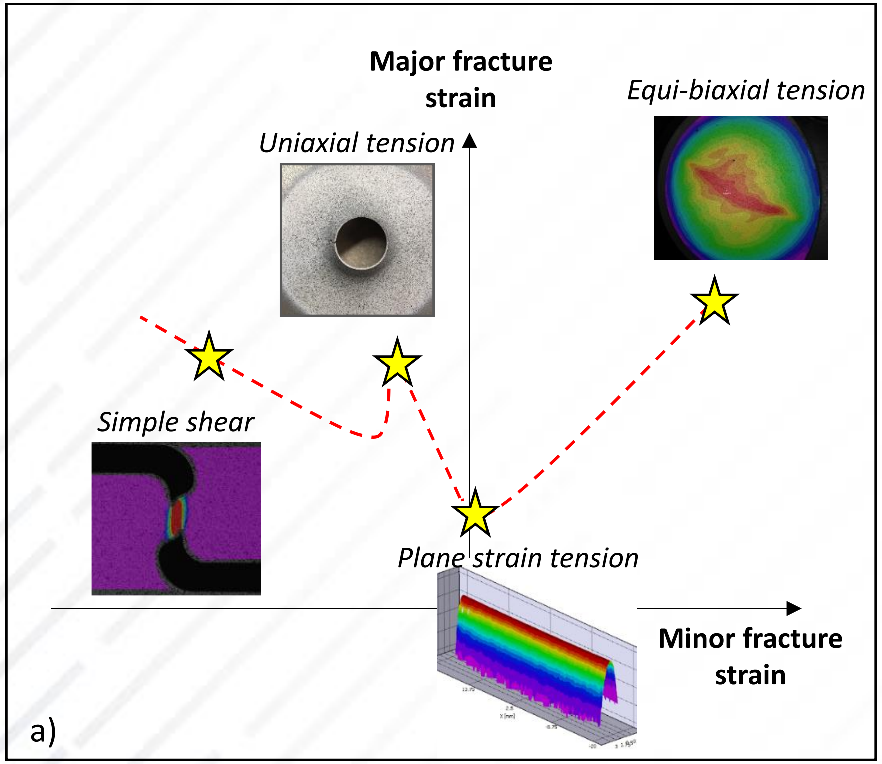


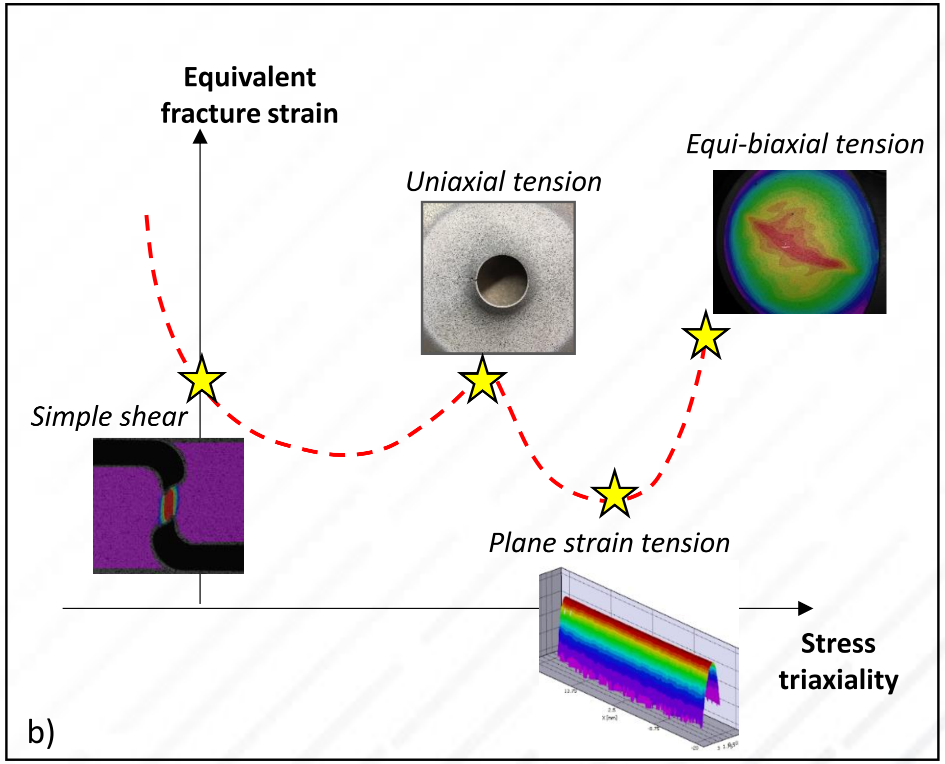


Fracture Characterization

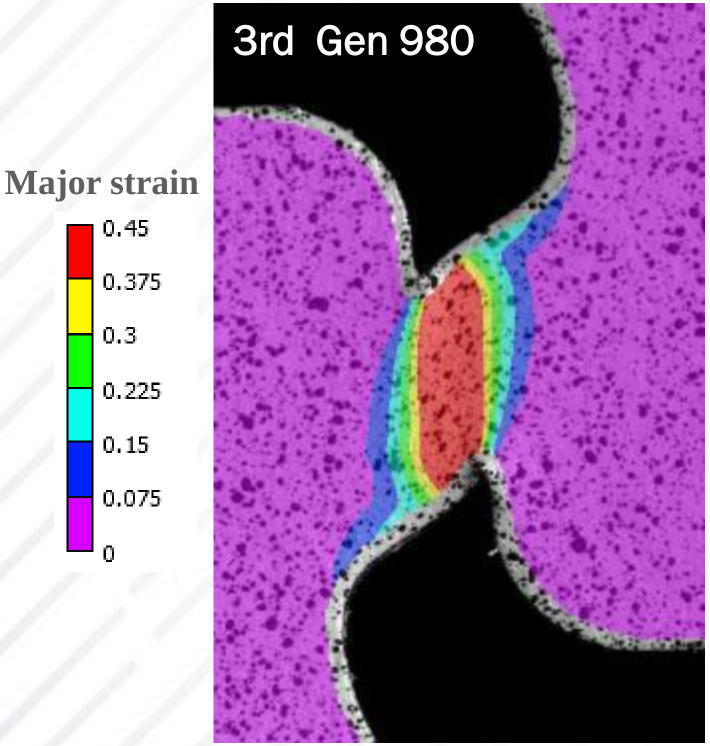
OVERVIEW FRACTURE CHARACTERIZATION

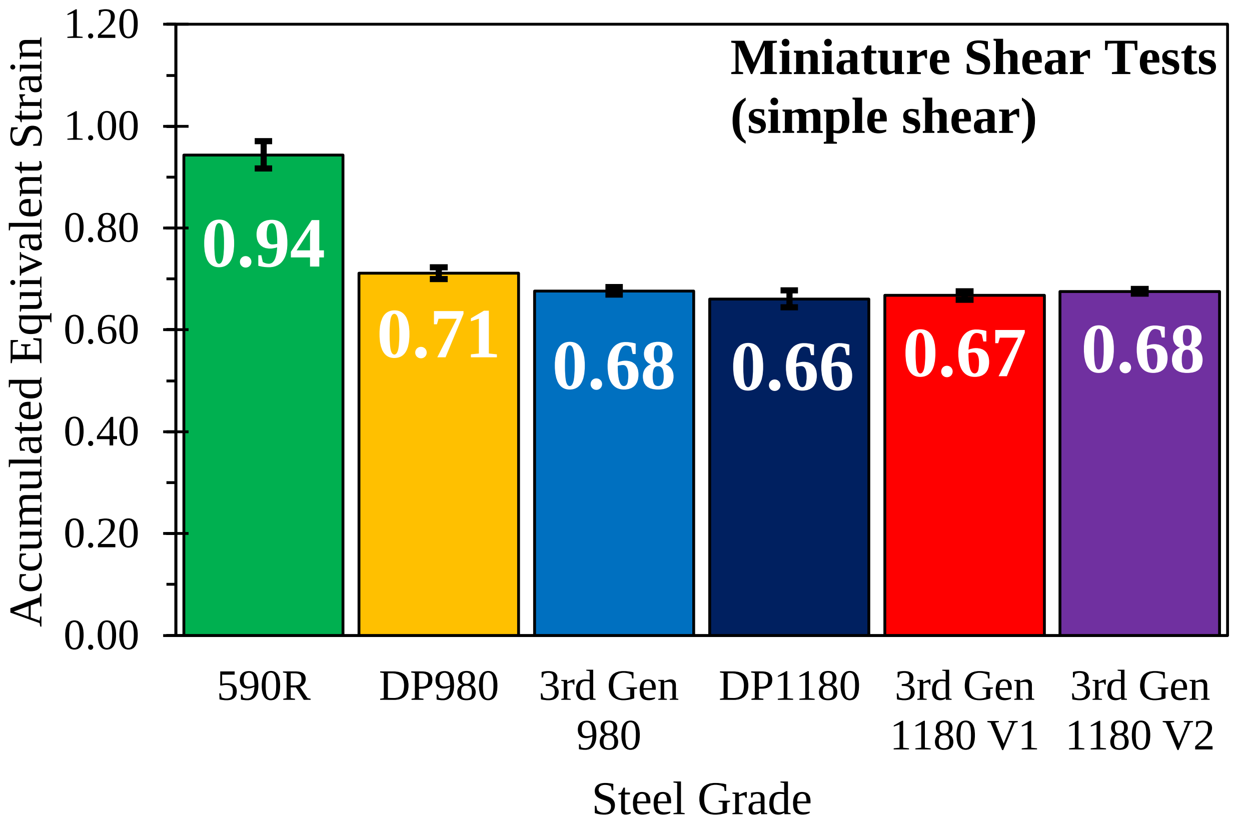
Selection of 4 plane stress experiments to characterize material failure under primary stress states





FRACTURE IN SIMPLE SHEAR

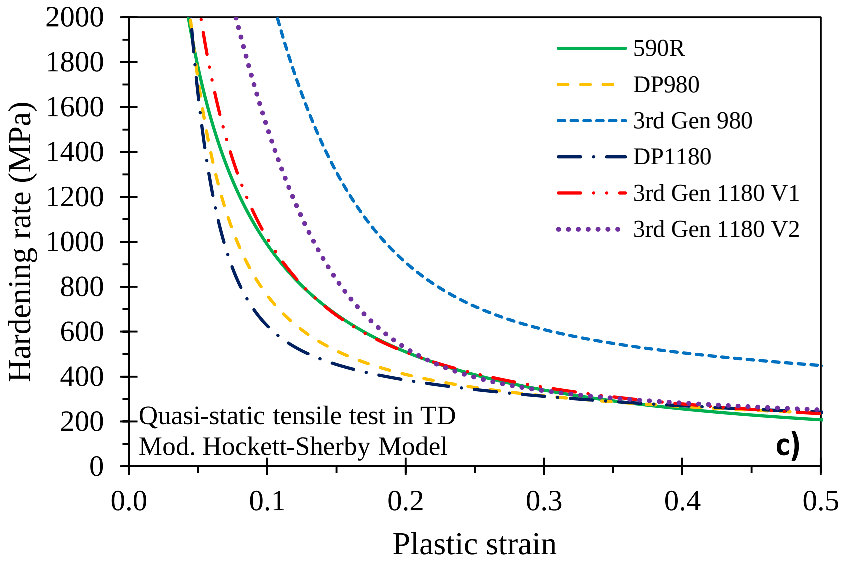


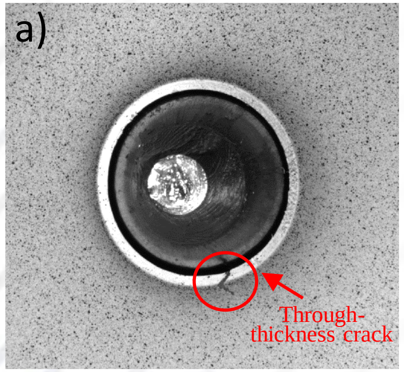


Shear performance of DP and 3rd Gen steels appears to be comparable

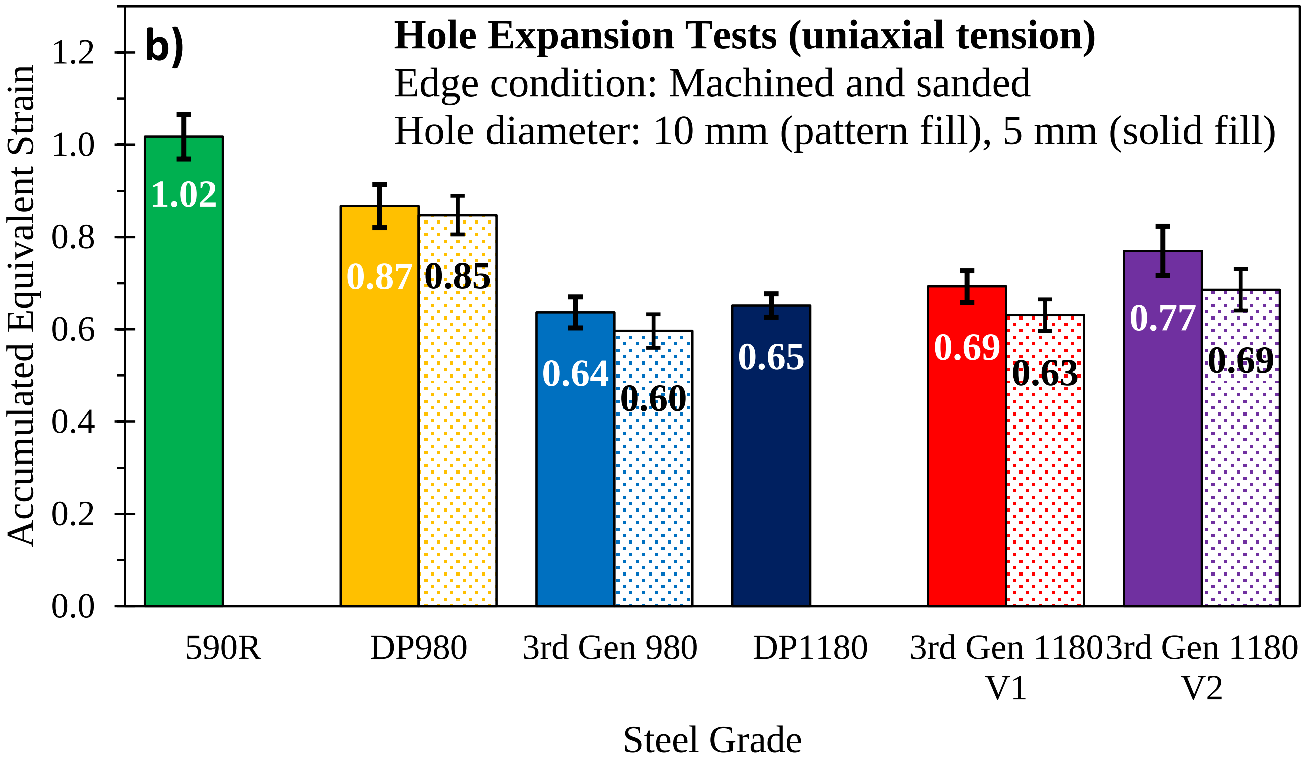
Potential for premature edge fracture in shear tests but not obvious in tests

FRACTURE IN UNIAXIAL TENSION





3rd Gen 1180 V1,
10 mm initial hole size

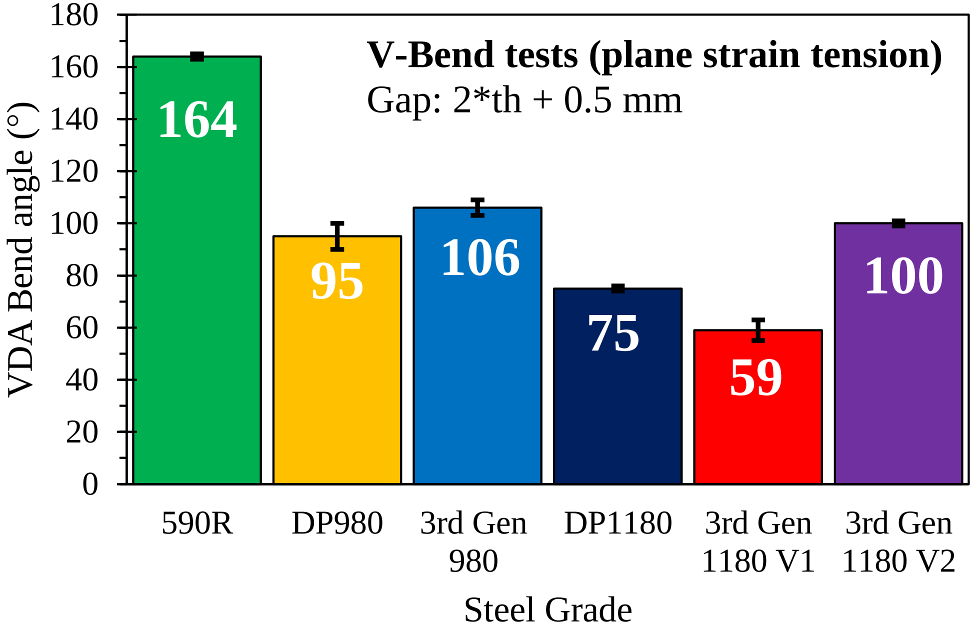


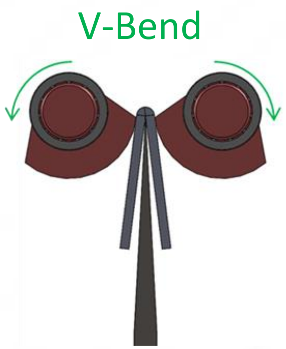
DP980 showed higher edge formability compared to grade of 3rd Gen 980 on project

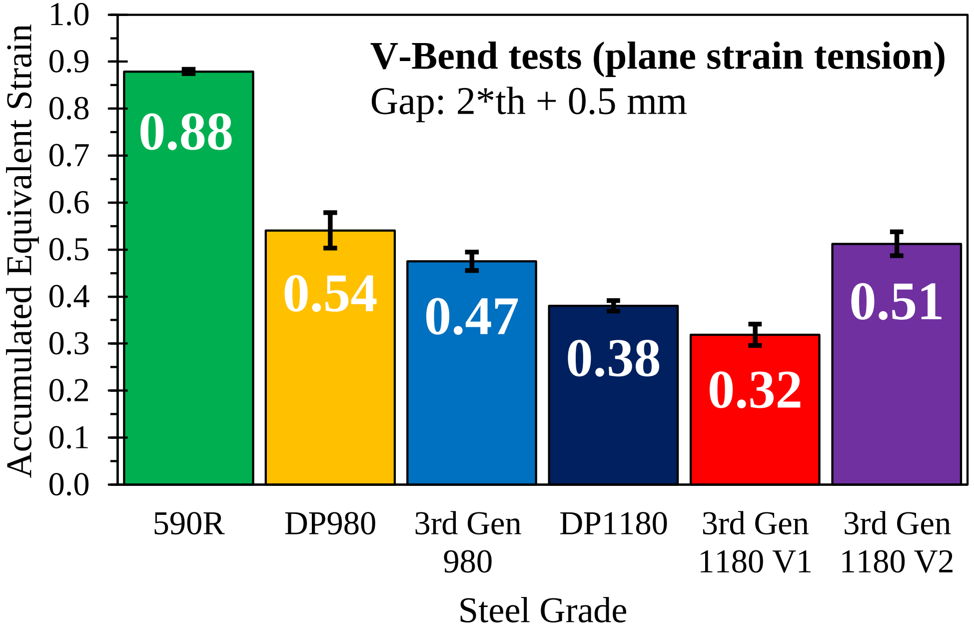
Higher hardening rate of 3rd 980 might cause higher stress differential between phases

FRACTURE IN PLANE STRAIN TENSION

Inverted VDA 238-100 V-Bend frame equipped with DIC utilized





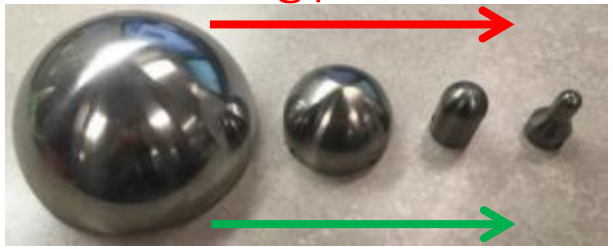


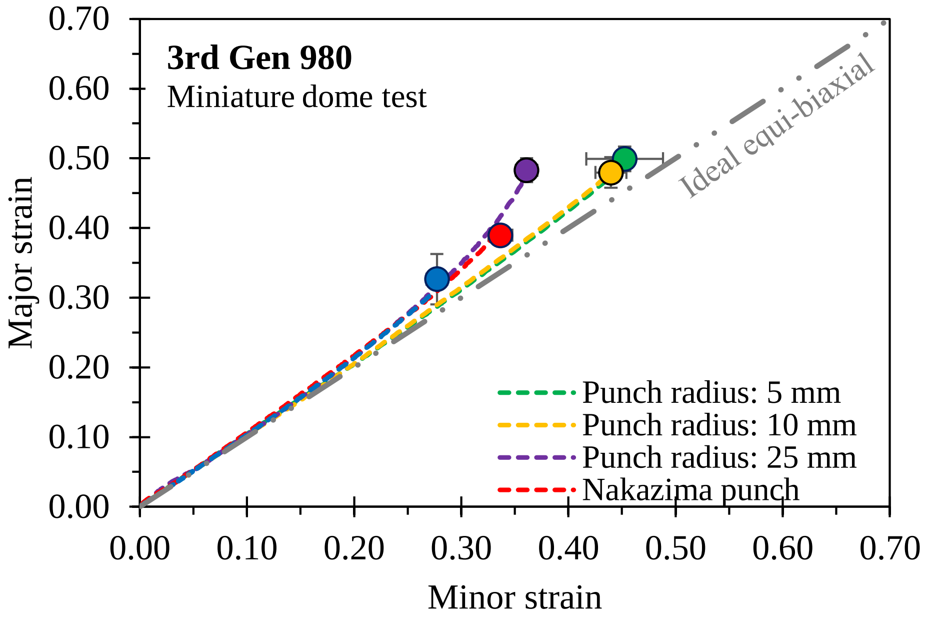
Comparable performance of 3rd Gen 1180 V2 to DP980

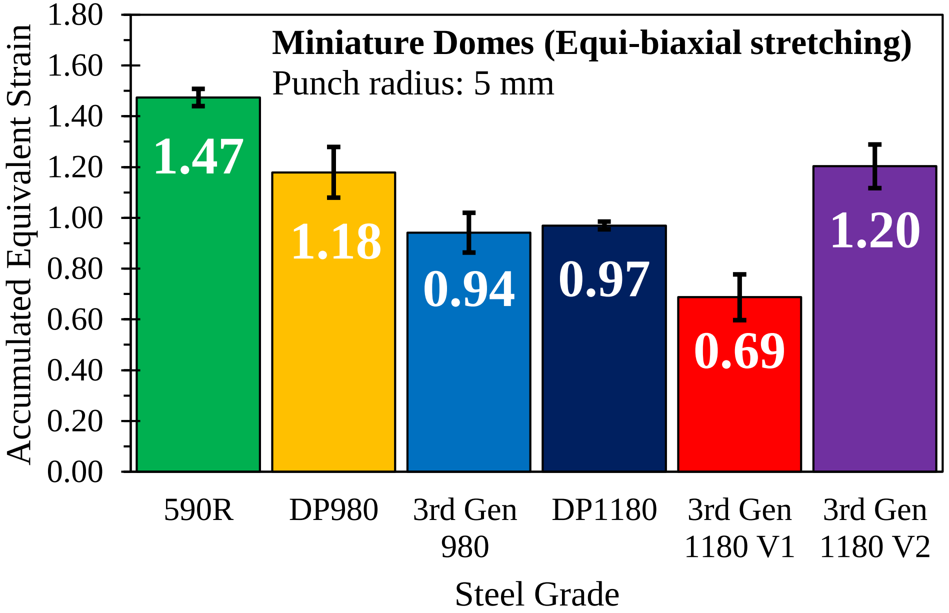
Fracture performance between 3rd Gen steel of same nominal strength can vary markedly

Ref. 10

FRACTURE IN BIAXIAL STRETCHING







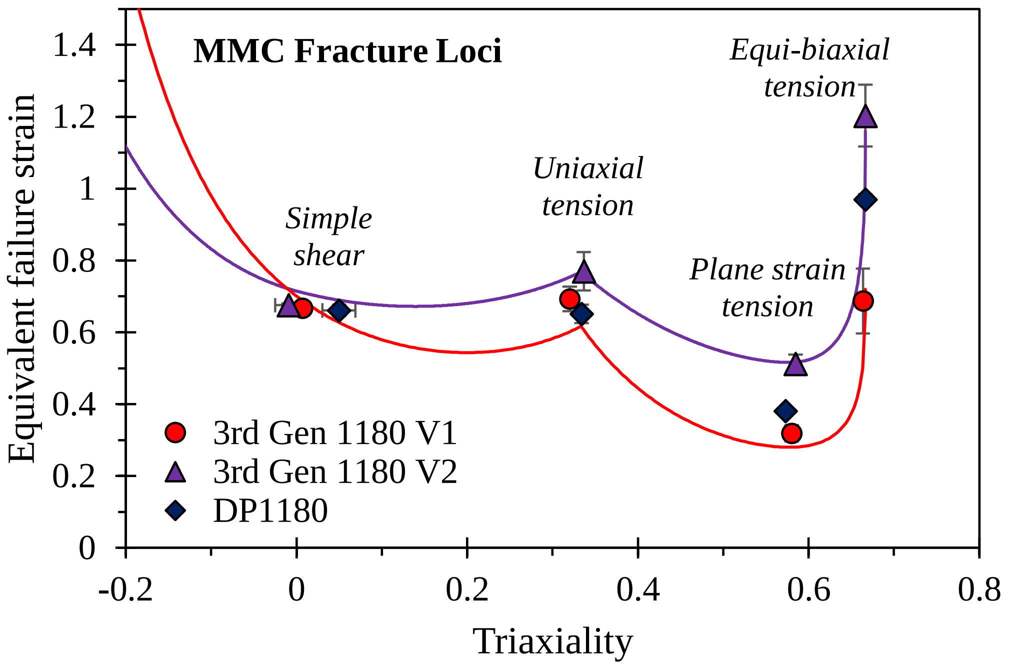
Superior performance of 3rd Gen 1180 V2 over V1

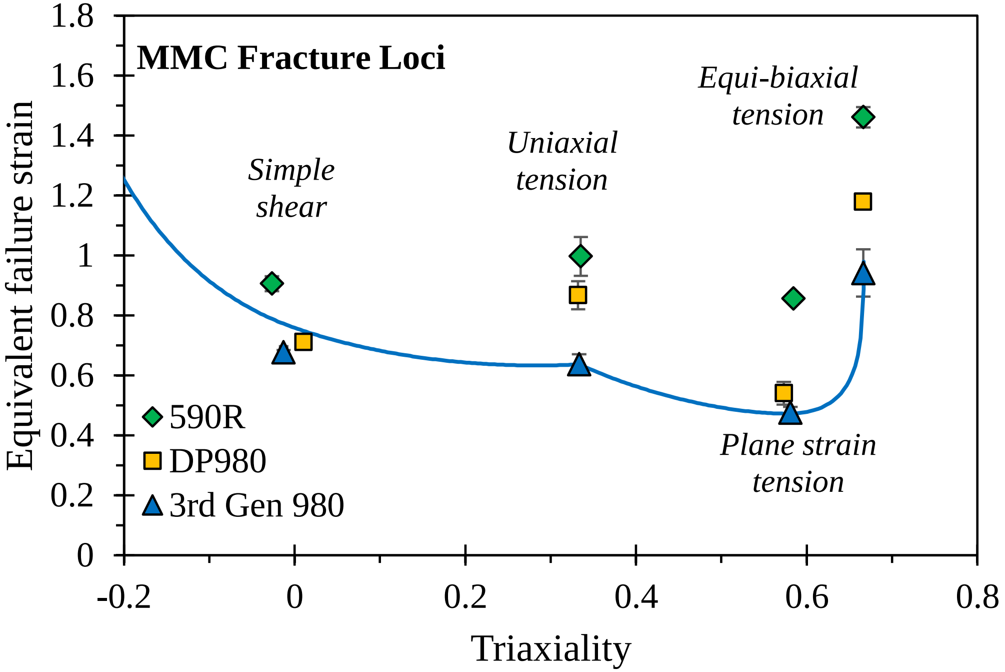
Comparable to performance of DP980

PLANE STRESS FRACTURE LOCI OF AHSS

Plane strain performance is critical for structural performance

→ *1180 grades: 3rd Gen can be similar to DP or significantly better*



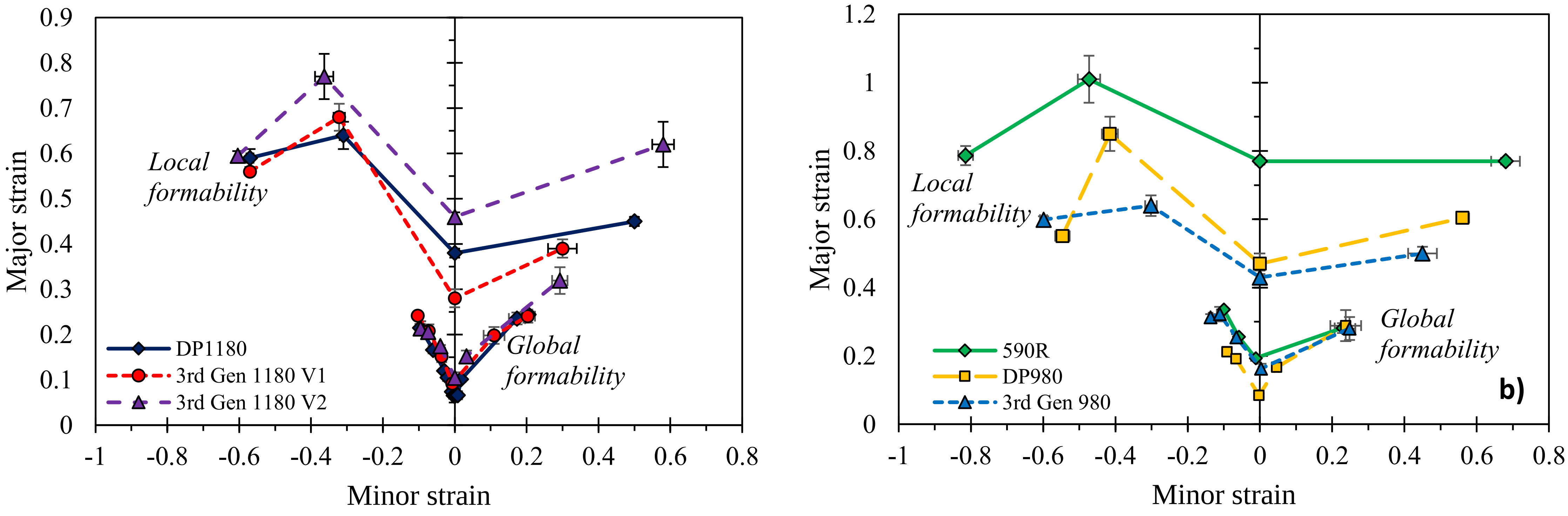


Similar fracture strains between the optimized DP980 and 3rd Gen 980

→ *Formability of 3rd Gen 980 was markedly better than DP980 for this project*

LOCAL VS. GLOBAL FORMABILITY

3rd Gen 1180 V1 and V2 had similar global formability with markedly superior local formability for the 3rd Gen 1180 V2

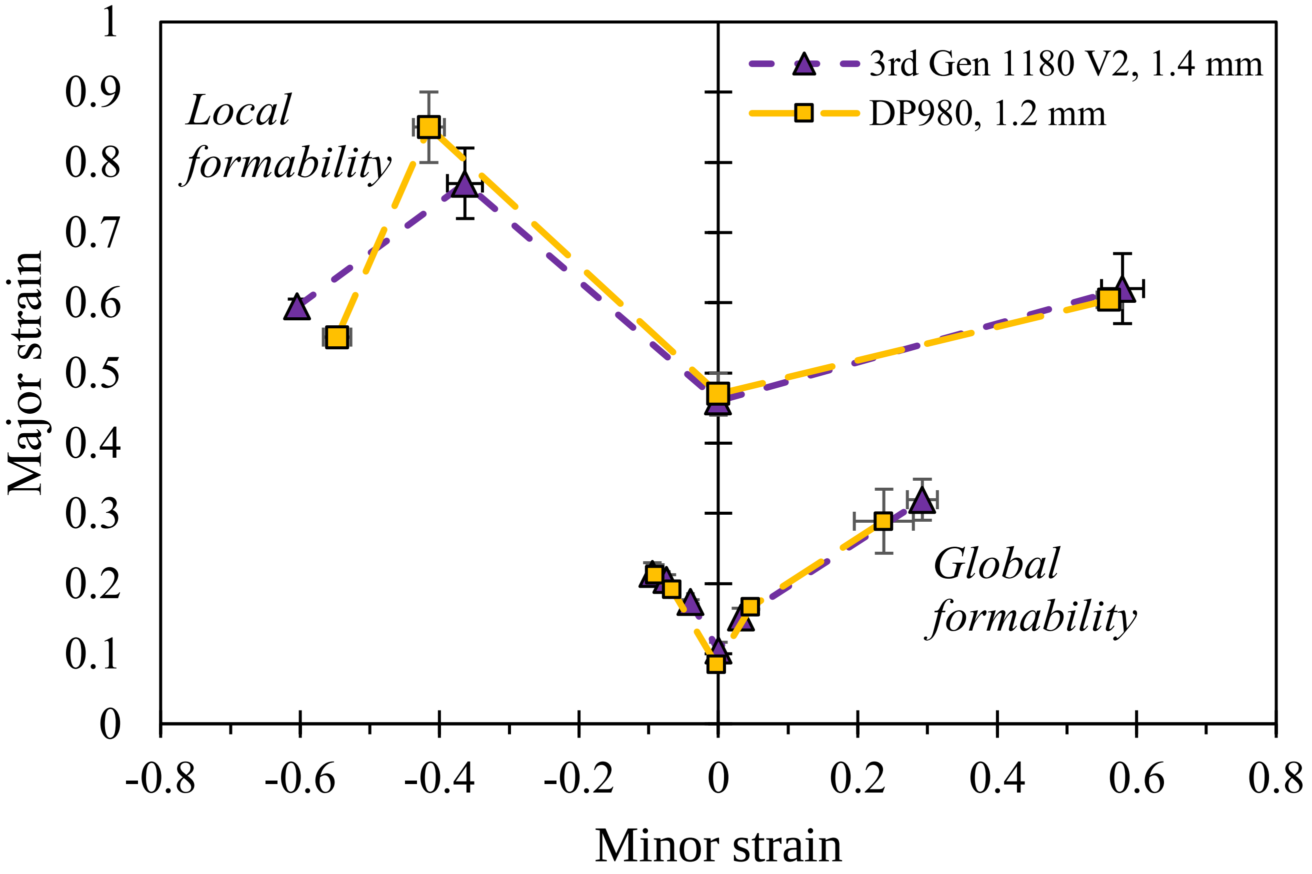


3rd Gen 980 had clearly superior global formability over DP980 but comparable or slightly lower fracture strains

POTENTIAL OF 3RD GEN STEELS

With respect to mechanical performance in forming and fracture:

→ *3rd Gen 1180 V2 has potential to replace current DP980 steel*



Application to B-Pillar Technology Demonstrator

APPLICATION TO B-PILLAR TECHNOLOGY DEMONSTRATOR

Modify geometry of hot stamped TWB B-pillar for mid-sized SUV to 3rd Gen

Developed with HRA, UW and Bowman Precision Tooling

Successful forming and proof-of-concept for CAE toolkit!

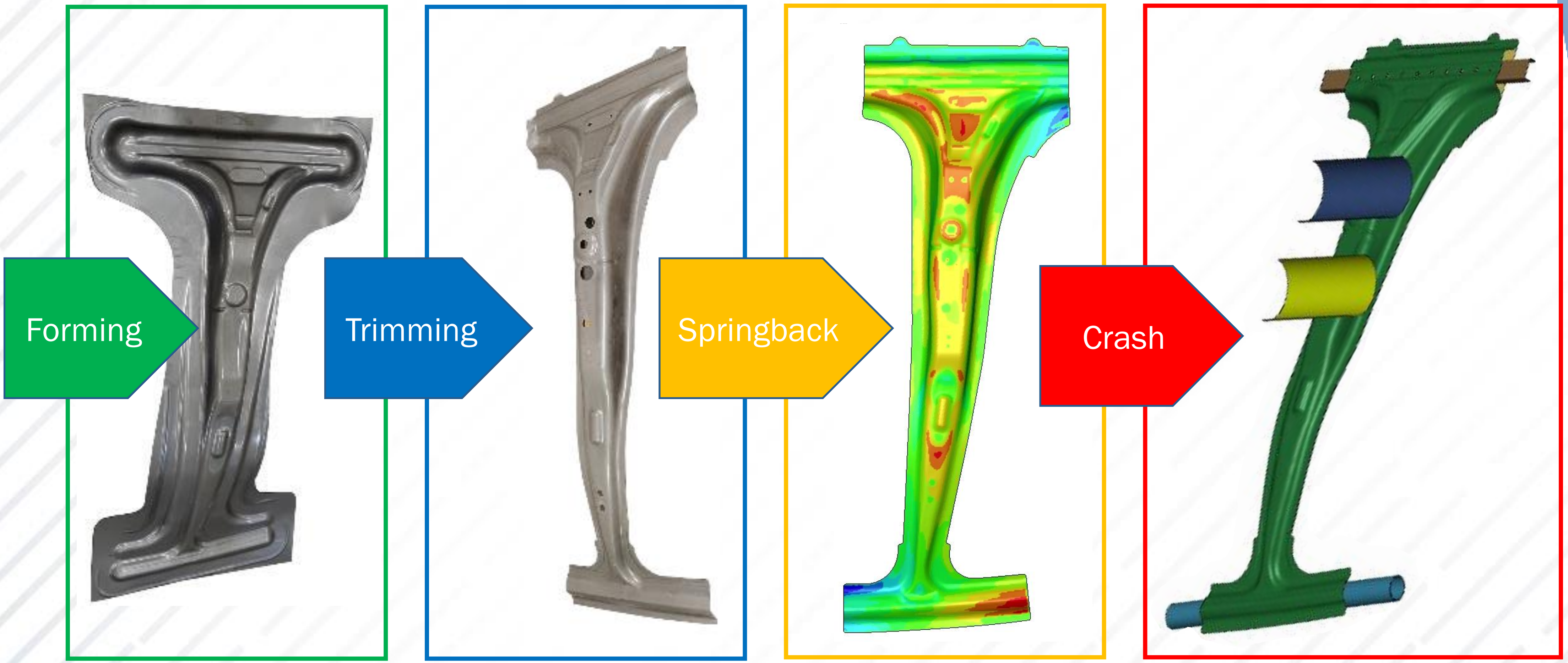
Not a production B-pillar, is representative technology demonstrator

3rd Gen 980

3rd Gen 1180

Ref. 11

RESEARCH SCOPE



Ref. 11

FORMING TRIALS AT BOWMAN

Tooling design, fabrication, stamping and part scanning by Bowman precision tooling
- Simpac 1500-ton Tryout press (2.5 m x 6 m)
- 5-axis CNC machining of B-pillar tooling
- Autoform used to design B-pillar tooling and springback compensation

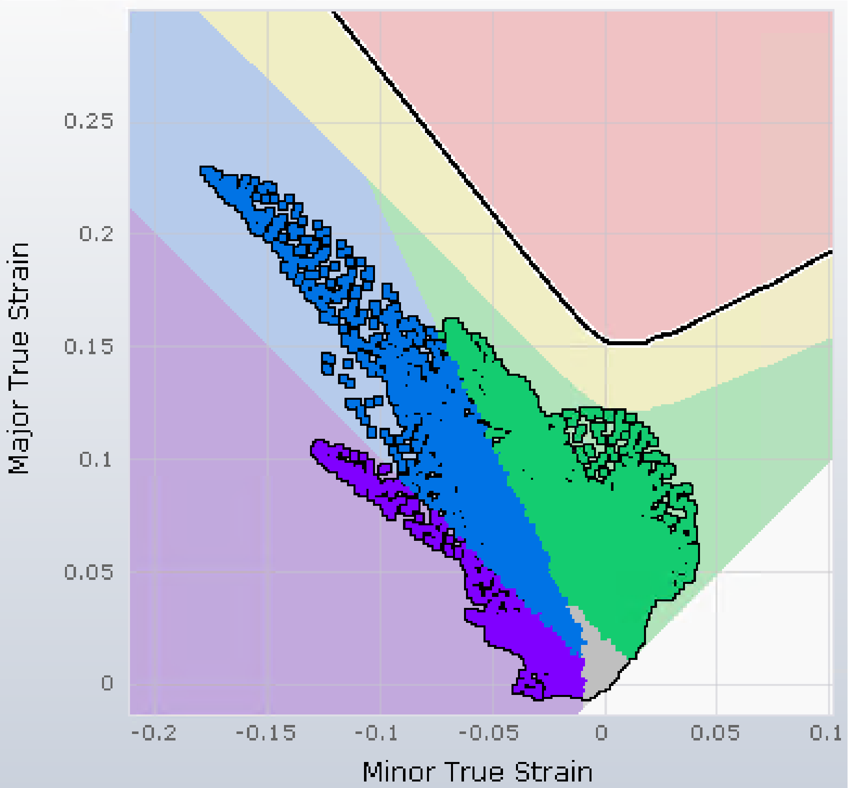


Ref. 11

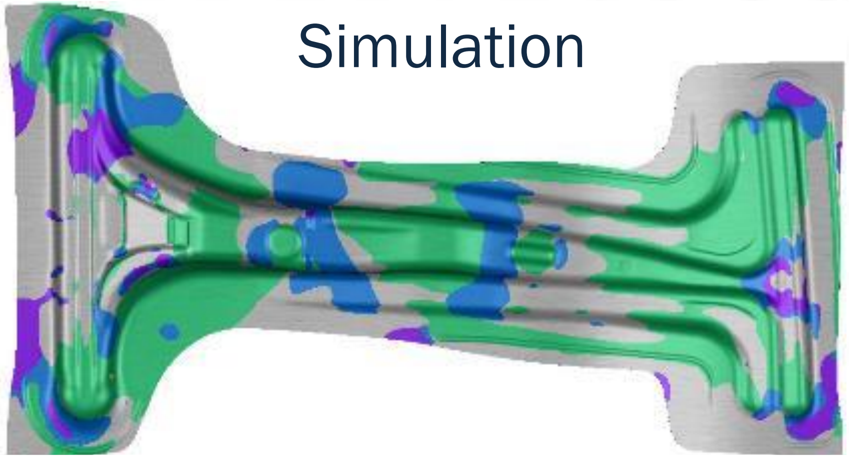
FORMING VALIDATION: 3RD GEN 980

Forming simulations predicted that 3rd Gen 980 forms successfully

Forming trials were consistent with simulations results → no splitting



Simulation

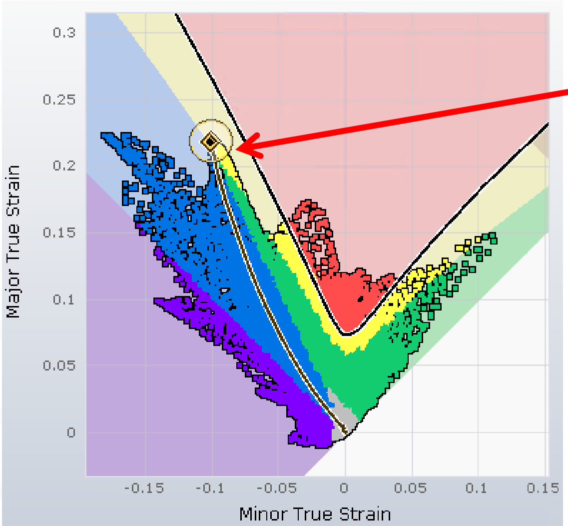


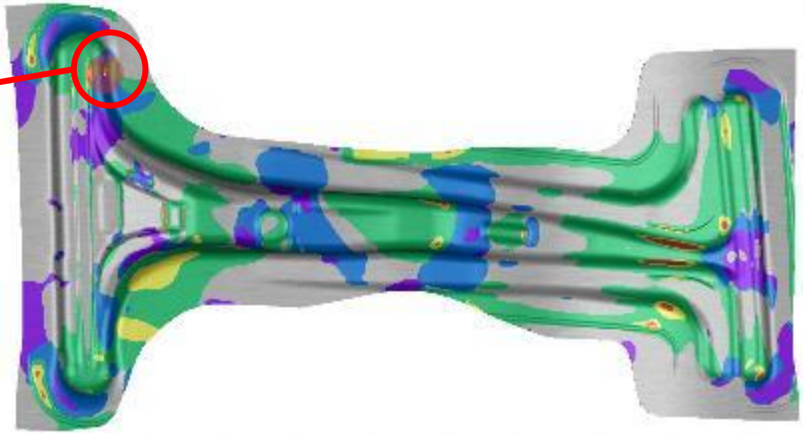
Forming trials

Ref. 11

FORMING VALIDATION: 3RD GEN 1180 V1

Predicted splitting of the 3rd Gen 1180 V1 in multiple locations
Forming trials split at only one location (in-plane stretching)





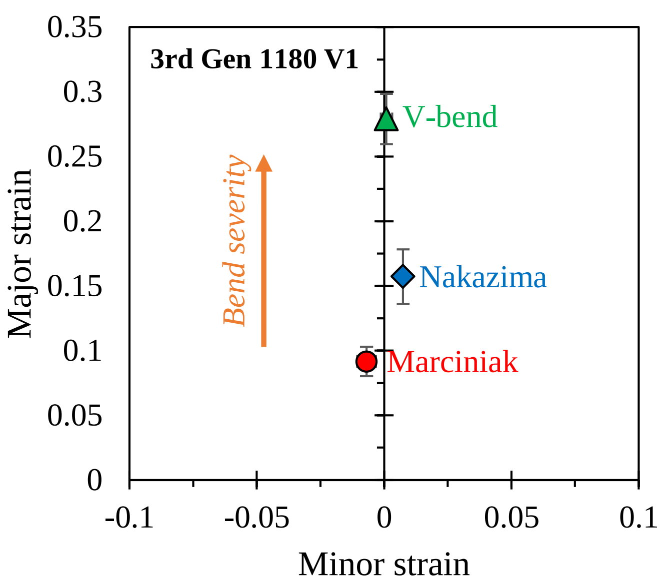
B-Pillar sidewall
(in-plane stretching)

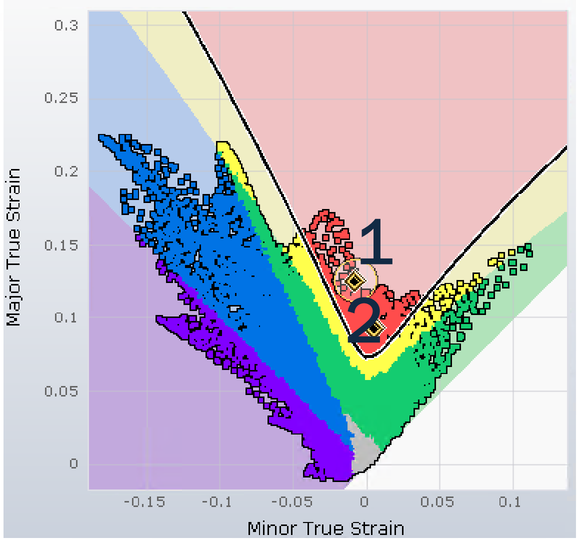
Ref. 11

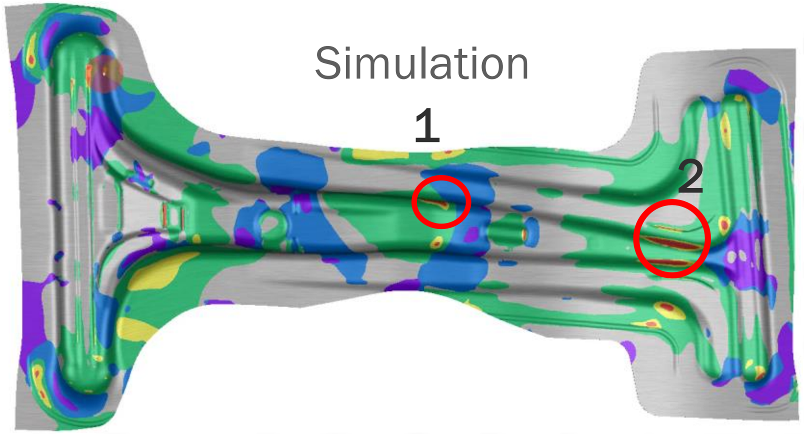
FALSE POSITIVES: 3RD GEN 1180 V1

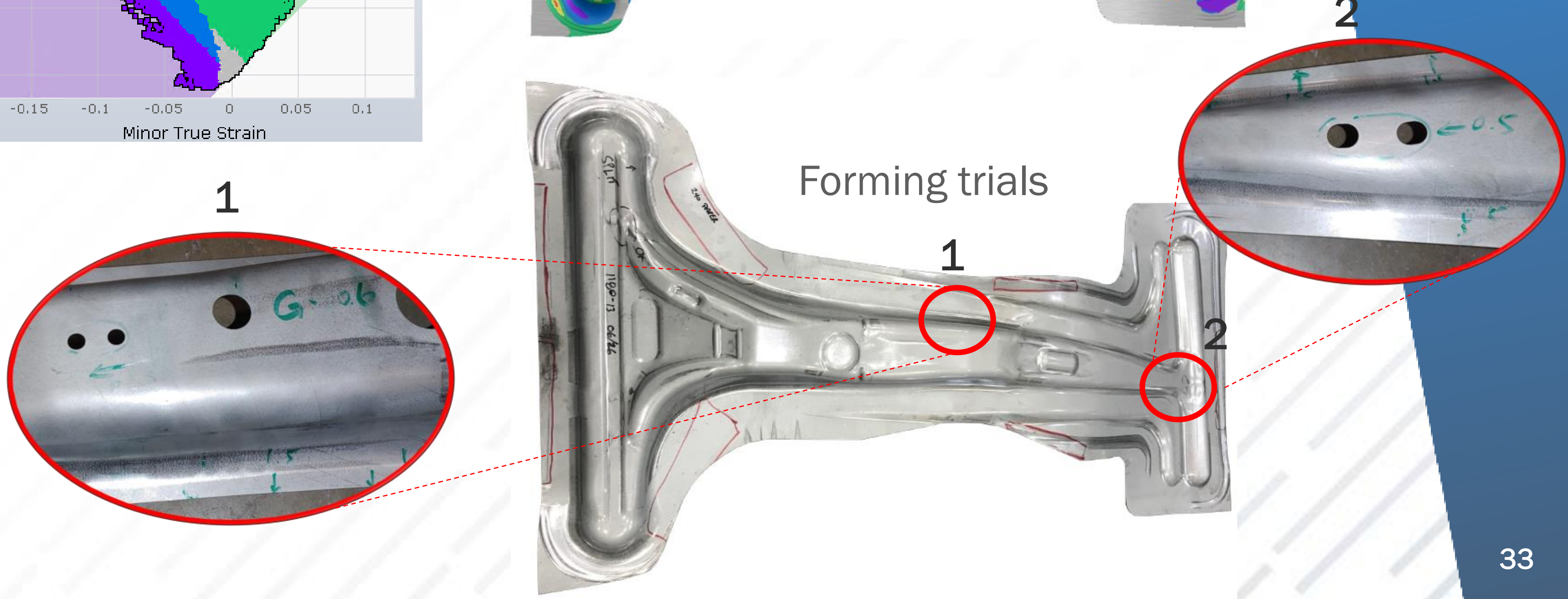
Predicted splits in plane strain tension are false positives

→ Located along part radii with appreciable bending and tool contact





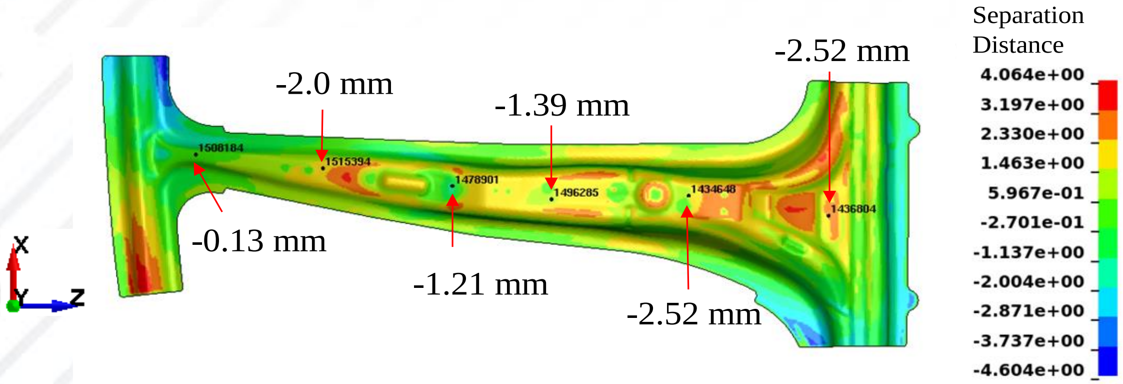




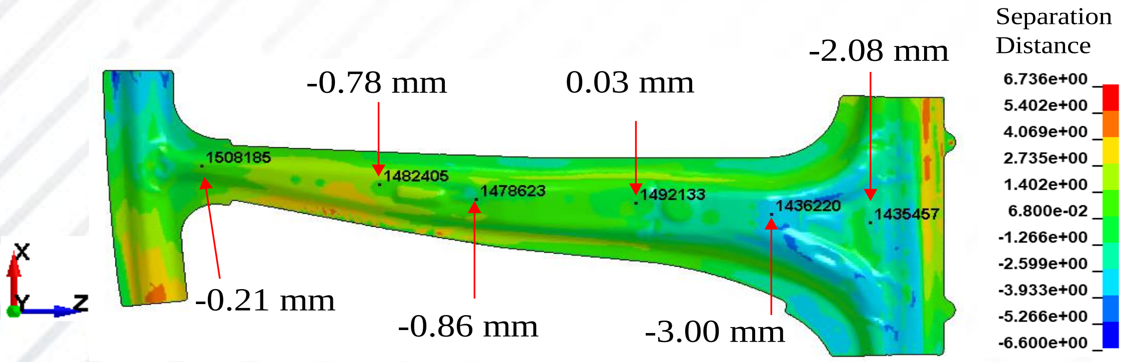
SPRINGBACK EVALUATION

Tooling compensation was performed in Autoform including kinematic hardening

- Part scans provided by Bowman Tooling Precision



3rd Gen 980



3rd Gen 1180 V1

Simulation comparisons with part scans are approximately within ± sheet thickness (1.4 mm)

Advanced kinematic hardening model will be added in future springback analysis within LS-DYNA

CONCLUSIONS AND NEXT STEPS

Comparable anisotropy and chord modulus evolution among studied 3rd Gen steels and DP steels

Rate sensitivity and local formability greatly varies between studied 3rd Gen steels of the same strength level
→ 3rd Gen 1180 V2 has potential to replace regular DP980

Forming of technology demonstrator could successfully be predicted for 3rd Gen 980 using simple and deterministic BWx model, springback can be improved

Forming prediction too conservative in bending zones for 3rd Gen 1180 V1
→ Dynamic instability model in development

Evaluate 3rd Gen steels in component tests → GDIS 2022

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CLIFFS

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