GREAT DESIGNS IN STEEL
TWENTY YEARS

CHARACTERIZATION OF 3RD GEN AHSS TOWARDS RELIABLE FORMING AND SPRINGBACK

Kidambi Kannan
AutoForm Engineering USA, Inc.

PROJECT TEAM

University of Waterloo
Prof. Cliff Butcher
Jacqueline Noder – PhD Candidate
Edward Gutierrez – MASc Candidate

Bowman Precision Tooling
Jamie Bowman – President
Neil Parker – Engineering Manager

Honda Manufacturing & Development America (HMDA)
Jim Dykeman – Retired
Skye Malcolm
Cameron O’Keeffe
Tarek Belgasam

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

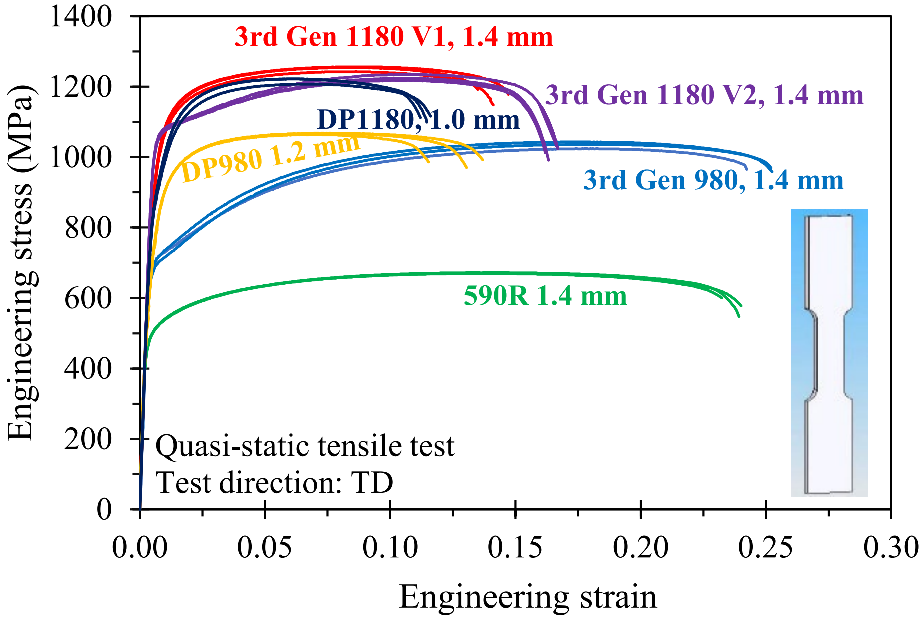
Perform dynamic B-pillar impact tests to evaluate CAE toolkit and methodology to design 3rd Gen steel components (GDIS 2022)

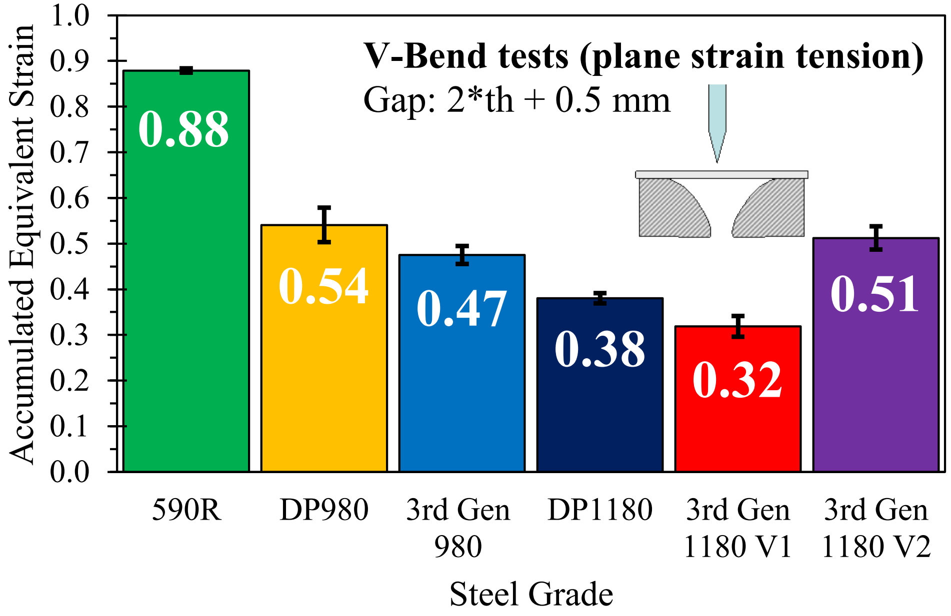
Butcher, et al (2021). Formability and Fracture Validation of 3rd Gen Steels, Great Designs in Steel 2021

Extension of above project towards following objectives:

- Representation of Material and Forming Process – Best Practices
- Comparing Simulation Outcomes to Physical Panels

MATERIAL PERFORMANCE





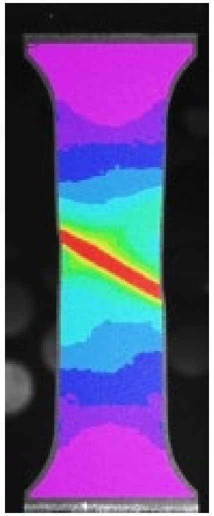
Grade	Nominal sheet thickness (mm)	Yield strength (MPa)	Ultimate Tensile Strength (MPa)	Yield-to-UTS ratio	Uniform Elongation UE (%)	Total Elongation TE (%)
590R	1.4	490 (±2)	671 (±1)	0.73	19.9 (±0.3)	23.7 (±0.4)
DP980	1.2	735 (±2)	1065 (±3)	0.69	7.8 (±0.2)	13.7 (±0.5)
3rd Gen 980	1.4	681 (±8)	1034 (±10)	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)

B-Pillar Trials

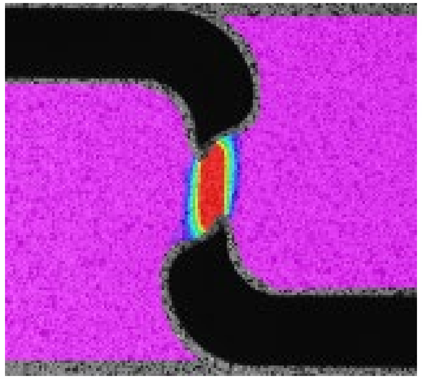
HARDENING CHARACTERIZATION

20 YEARS GDIS

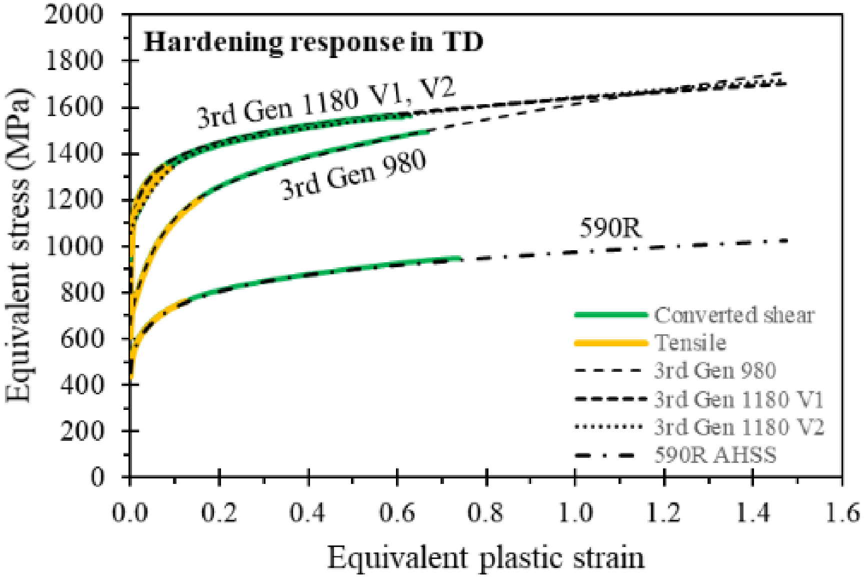
Isotropic hardening to large strains obtained using tensile and shear test data



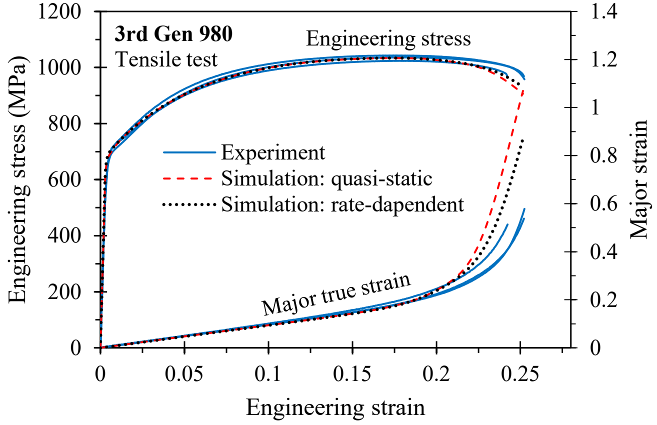
Tensile Test until UTS

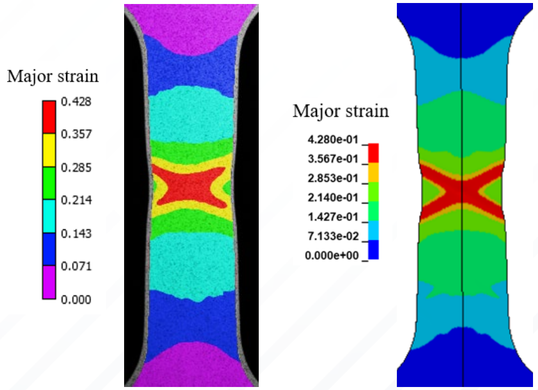


Simple Shear After Tensile UTS



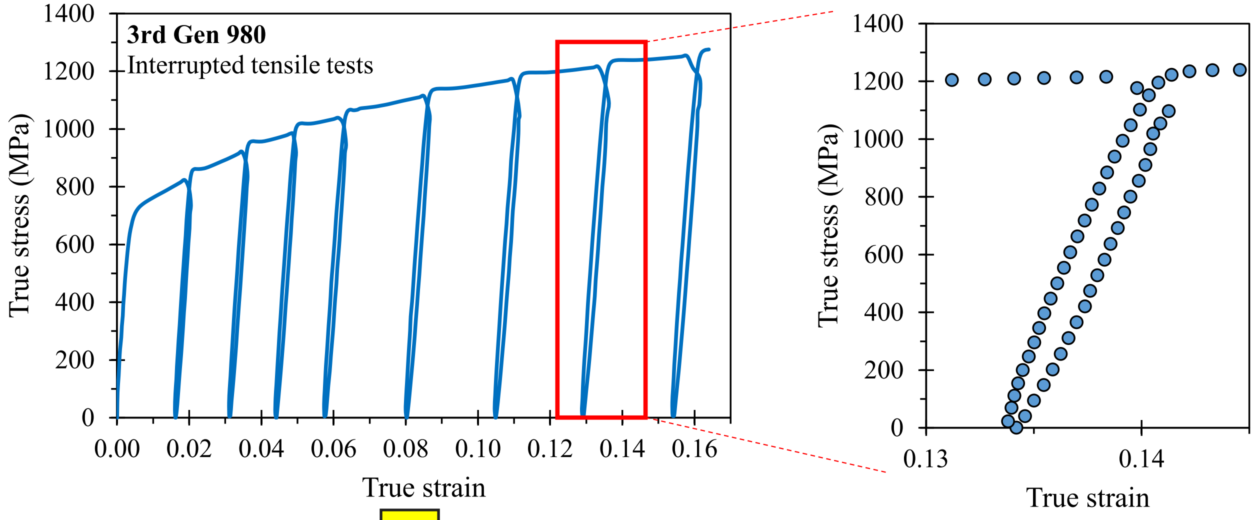
Accurate predictions in CAE of tensile test without inverse modelling

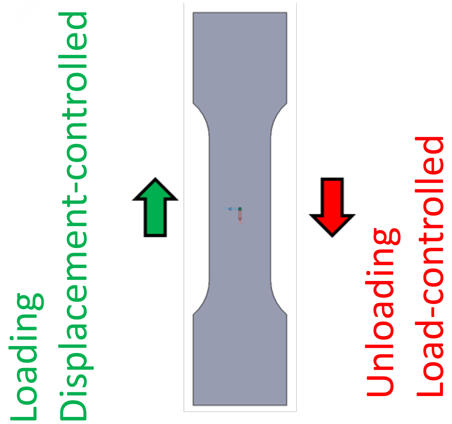




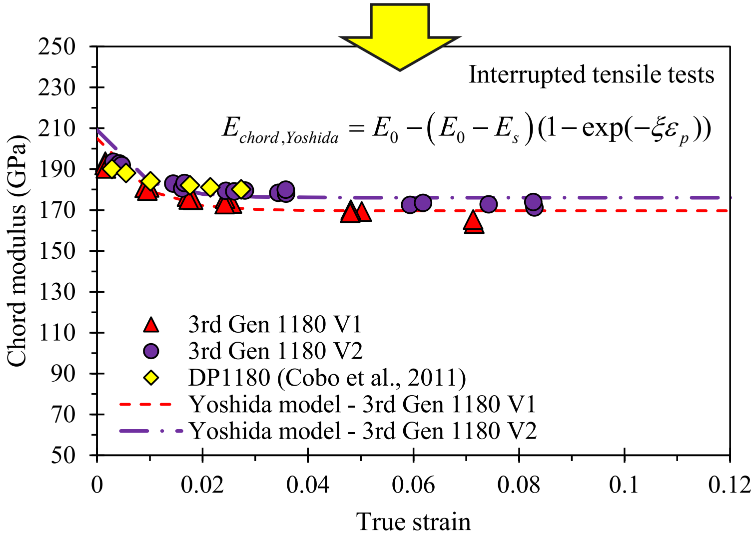
CHORD MODULUS CHARACTERIZATION

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

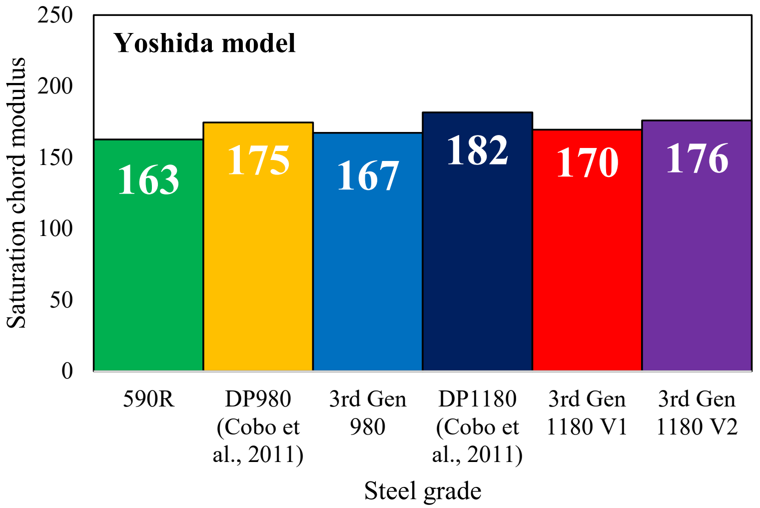




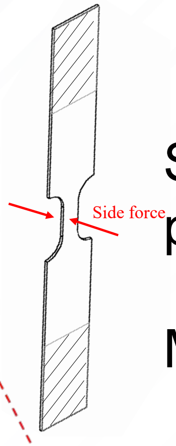
JIS No. 5 geometry



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

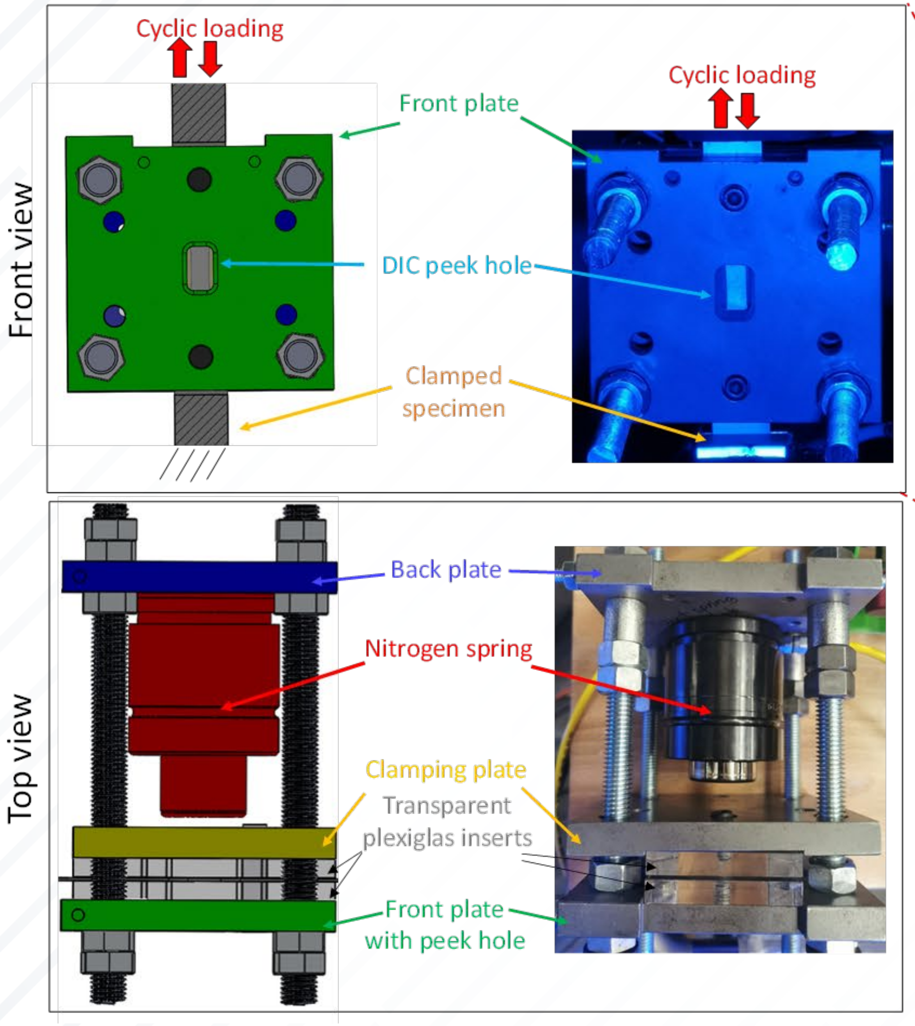


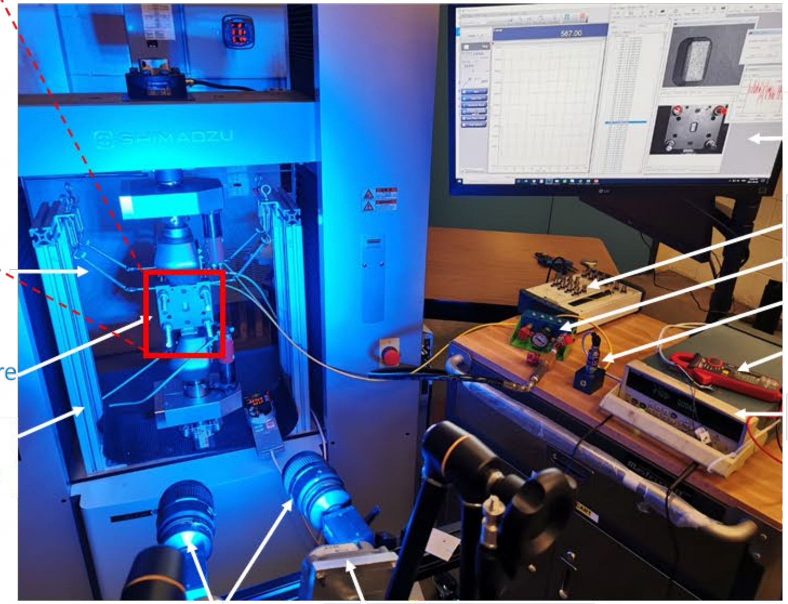
KINEMATIC HARDENING CHARACTERIZATION



Side force applied to the gauge area to prevent buckling in compression

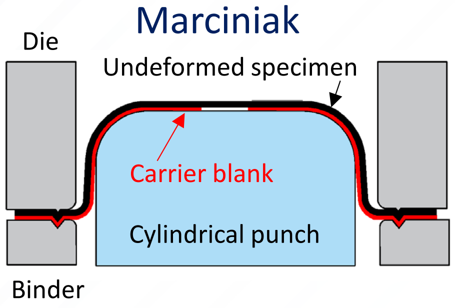
Magnitude of side force depends on material

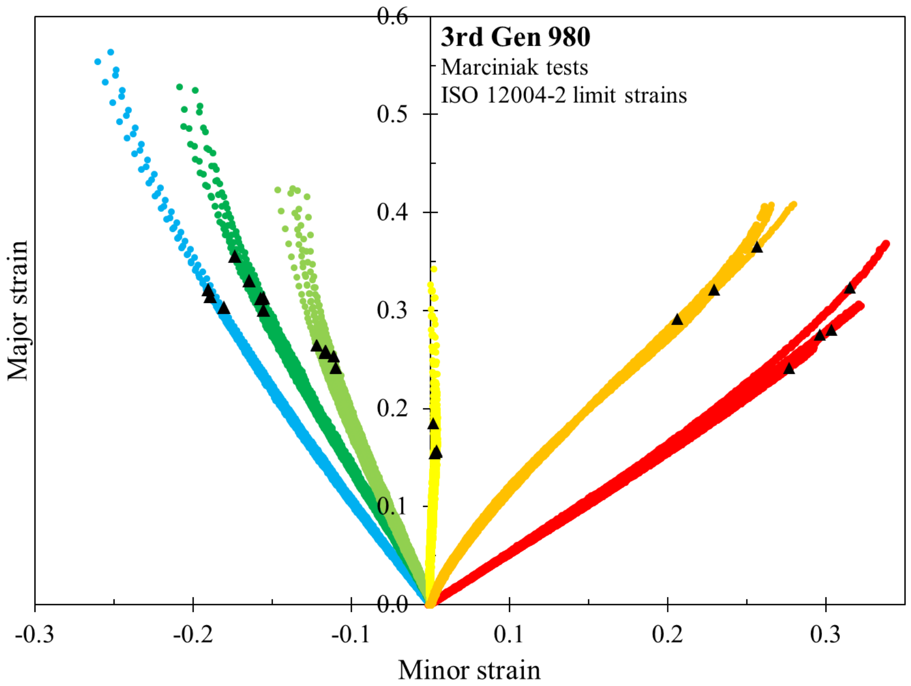


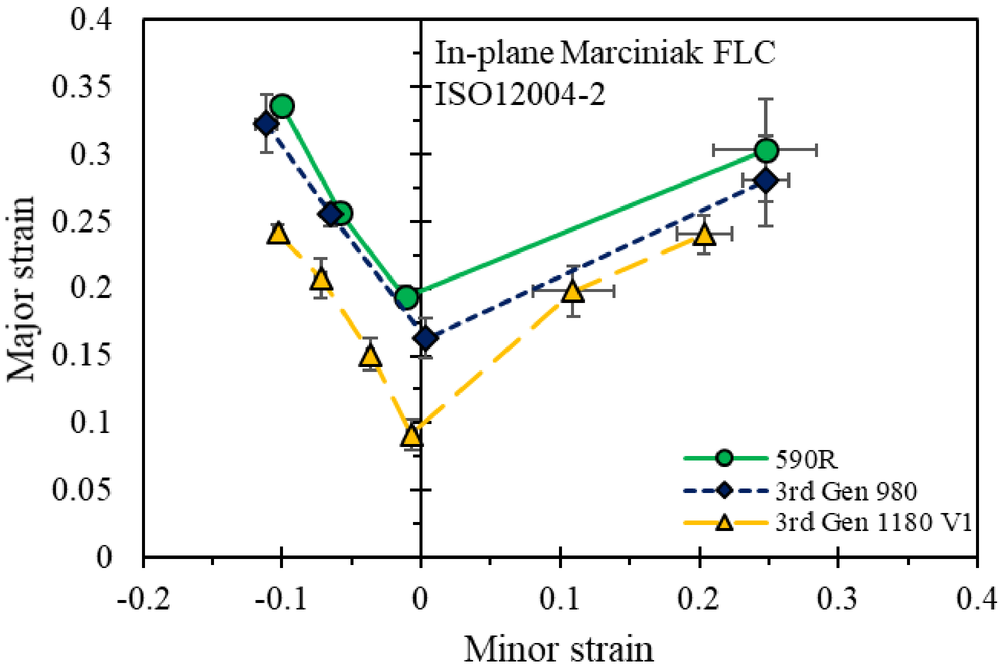


FORMABILITY CHARACTERIZATION

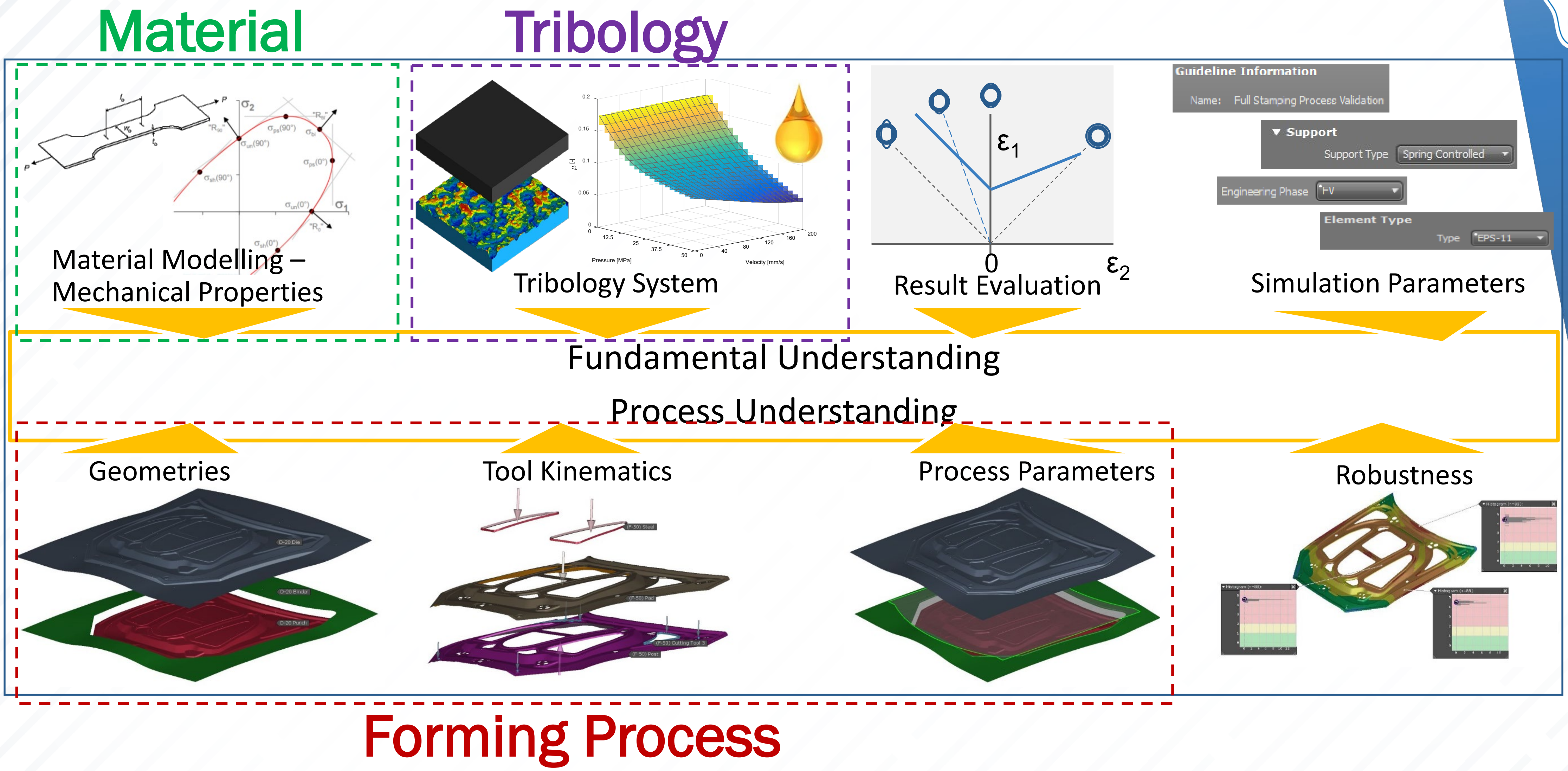
In-Plane FLC obtained using Marciniak tests → Linear strain path, no tool contact or bending effects







ACCURATE DIGITAL MODEL



FORMING PROCESS

Draw – Laser Trim (Springback)

FORMING TRIALS AT BOWMAN

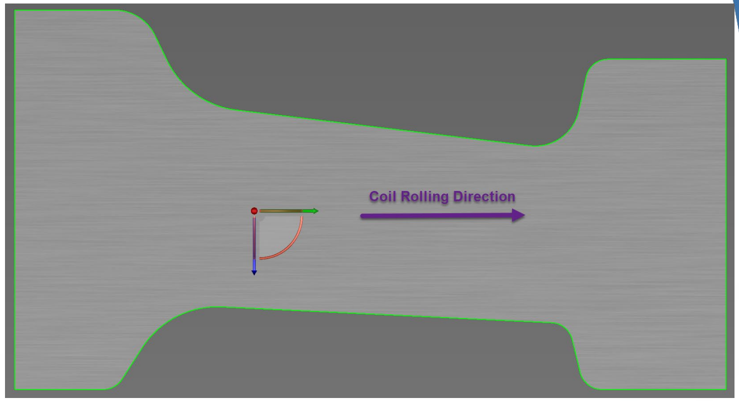
Tooling design, fabrication, stamping and part scanning by Bowman precision tooling

- 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

30

Gutierrez, J. E., et al (2021). Formability characterization of 3rd Gen advanced High-Strength steels, and Application to forming a B-pillar, SAE Technical Paper

- Binder Stroke 100mm
- Binder tonnage:
  275 tonf - 400 tonf
  over stroke



- 590R, 3rd Gen 980, and 3rd Gen 1180 blanks were stamped, trimmed and scanned

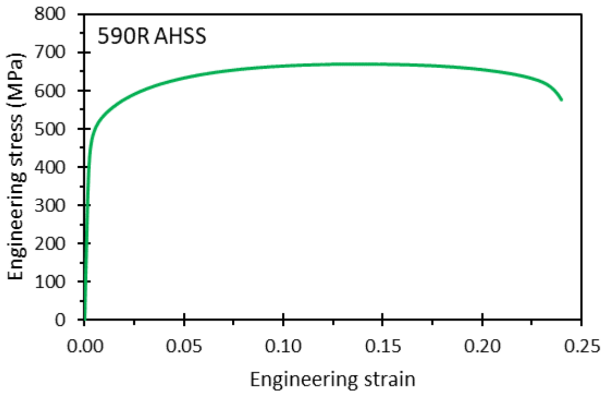
MATERIALS

- 590R, 3rd Gen 980, 3rd Gen 1180
- 1.4mm thick
- Essential components of sheet material behavior
  - Elastic Properties
  - Tensile and Kinematic Hardening Representations
  - Plastic Anisotropy (R-values)
  - Yield Surface Model

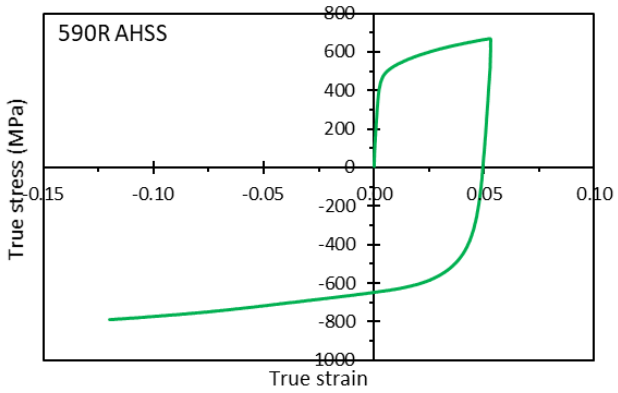
MATERIALS

- Essential *representation* of sheet material behavior

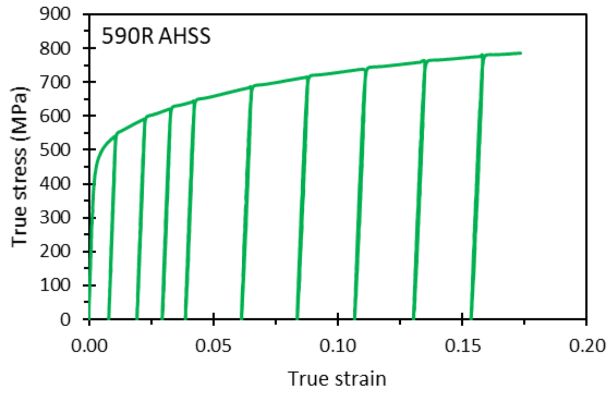
Tensile test



Cyclic tension-compression test

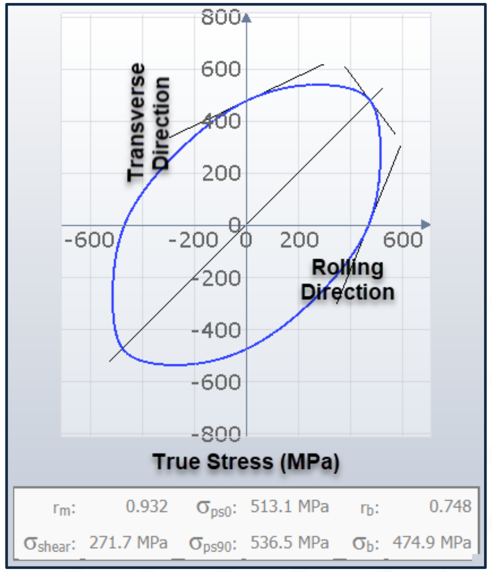


Interrupted tensile test

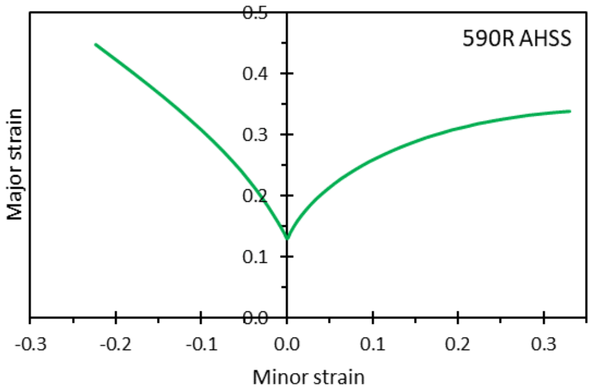


R-Values:

Rolling	0.675
Diagonal	1.076
Transverse	0.903



Forming Limit Curve



TRIBOLOGY

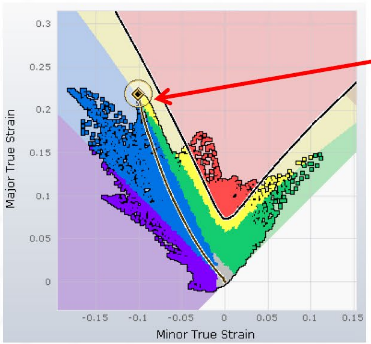
- Steady state friction coefficients were determined using the Twist-Compression-Test (TCT) for the following forming system:
  - Sheet metal (590R, 3rd Gen 980, 3rd Gen 1180 V1)
  - Lubricant / drawing oil CommDrawTM200 (Commonwealth Oil Corp., Harrow ON, Canada)
  - Tool steel Cr-Mo-Va, hardened to 53 HRC
  - Contact Pressure 25 MPa

- Steady-state / dynamic Coulomb Friction Coefficients determined were:
  - 590R: 0.11
  - 3rd Gen 980: 0.13
  - 3rd Gen 1180: 0.19

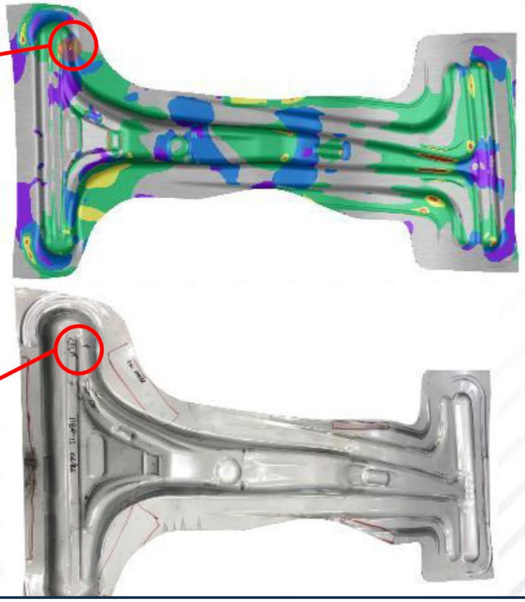
Noder et. al (2021). A Comparative Evaluation of Third-Generation Advanced High-Strength Steels for Automotive Forming and Crash Applications, Materials, 14, 4970. https://doi.org/10.3390/ma14174970

SIMULATION OUTCOMES

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

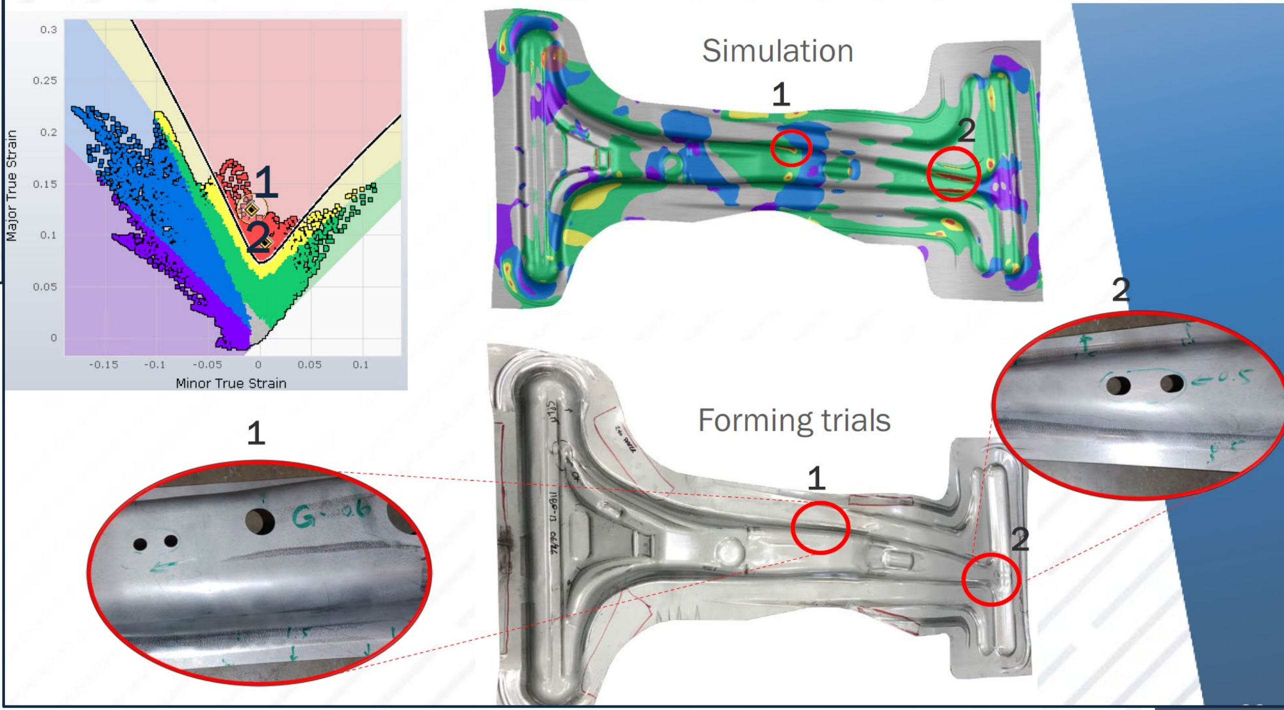


B-Pillar sidewall
(in-plane stretching)



Gutierrez, J. E., et al (2021). Formability characterization of 3rd Gen advanced High-Strength steels, and Application to forming a B-pillar, SAE Technical Paper

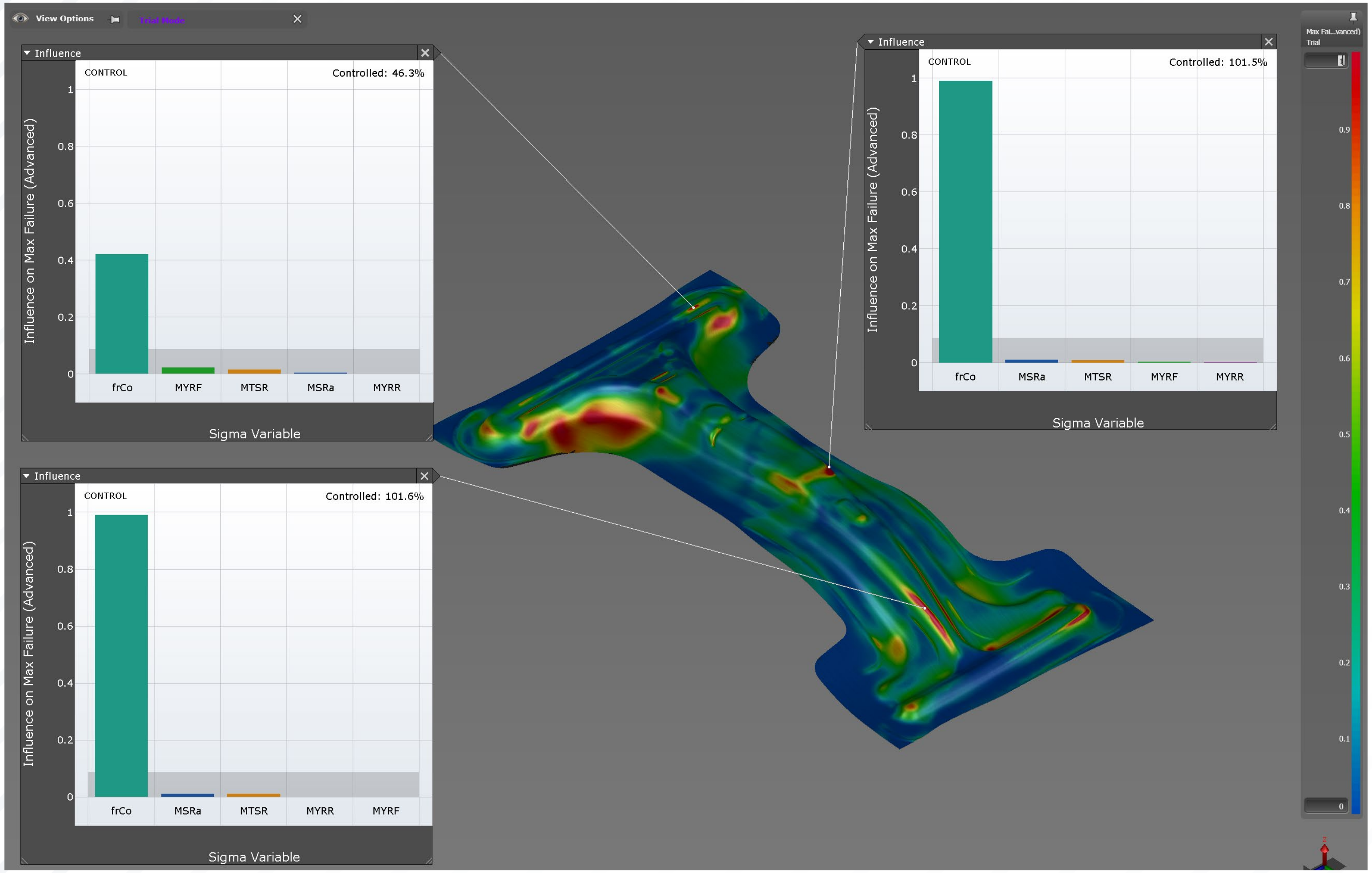
Predicted splits in plane strain tension are false positives
→ Located along part radii with appreciable bending and tool contact



- Material?
- Forming Process?
- *Tribology?*

TRIBOLOGY

Friction influence is strongly evident in study using AutoForm-Sigma



What is the correct Friction Coefficient?

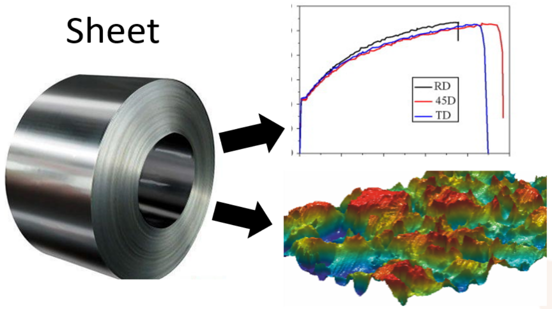
Build a Tribology System representative of forming process:

- Sheet metal coating and roughness
- Lubricant
- Tool material and roughness

TRIBOLOGY

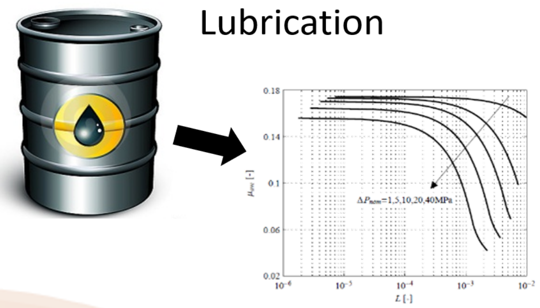
Tribology, friction and lubrication in sheet metal forming

Sheet



- Material properties
- Coating and surface finish
- Surface roughness

Lubrication



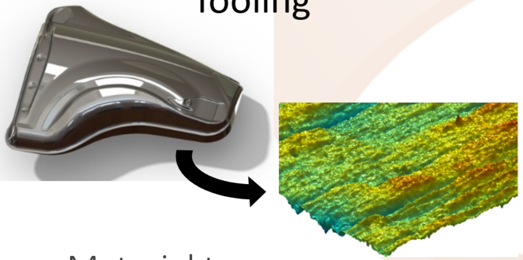
- Type of lubricant
- Liquid, hotmelt, etc.
- Amount and distribution

Tribology-system

μ

TriboForm

Tooling



- Material type
- Surface finish
- Surface roughness

Process

- Pressure
- Velocity / stroke rate
- Temperature
- Sheet deformation

TRIBOLOGY

Data / information available:

- Sheet surface roughness
- Sheet coating
- Lubricant brand name
- Tool Material

Data / information NOT available:

- Tool surface roughness
- Lubricant assumed similar to drawing oil
- Lubricant amount

Tribology system selected from TriboForm Library:

590R

General	
TriboForm Friction File	TF - Dual Phase HSS (UNC) - Draw Oil - To
Average Friction Coefficient	0.094
Sheet	
Group	Steel (Default)
Type	HSS (Dual Phase UNC)
Supplier	Default
Roughness Range	0.90 - 1.50
Surface Finish	EDT
Lubricant	
Group	Drawing Oil
Supplier Type	Default
Range	0.50 - 3.00
Tooling	
Type	Tool Steel
Surface Finish	Polished
ID	Default
Roughness Range	0.40 - 2.00

3rd Gen 980

General	
TriboForm Friction File	TF - Dual Phase HSS (UNC) - Draw Oil - To
Average Friction Coefficient	0.096
Sheet	
Group	Steel (Default)
Type	HSS (Dual Phase UNC)
Supplier	Default
Roughness Range	0.90 - 1.50
Surface Finish	EDT
Lubricant	
Group	Drawing Oil
Supplier Type	Default
Range	0.50 - 3.00
Tooling	
Type	Tool Steel
Surface Finish	Polished
ID	Default
Roughness Range	0.40 - 2.00

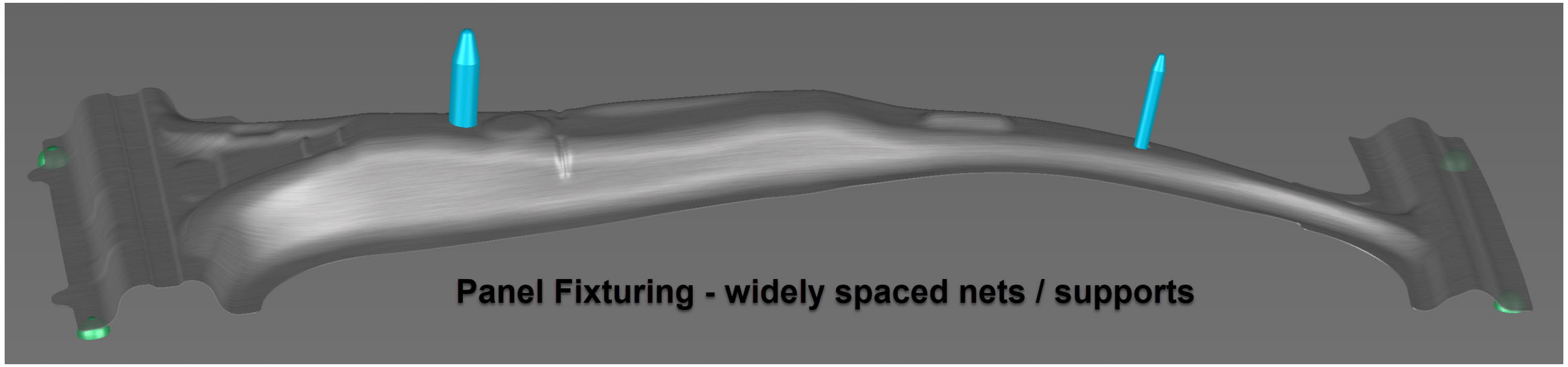
3rd Gen 1180

General	
TriboForm Friction File	TF - Bake Hardening HSS (EG coated) -
Average Friction Coefficient	0.098
Sheet	
Group	Steel (Default)
Type	HSS (Bake Hardening +EG)
Supplier	Default
Roughness Range	1.00 - 2.00
Surface Finish	EDT
Lubricant	
Group	Drawing Oil
Supplier Type	Default
Range	0.50 - 3.00
Tooling	
Type	Cast Iron
Surface Finish	Polished
ID	Default
Roughness Range	0.40 - 2.00

SIMULATIONS

Simulations run:

- With forming surfaces and process conditions from physical tryout
- With TriboForm friction for the respective tribology system for each blank material
- With and without Kinematic Hardening



Simulation outcomes compared to physical observations:

- Formability of the draw panel
- Forming tonnage for the draw
- Sprung panel after trimming best fit to respective scanned panel for each blank material

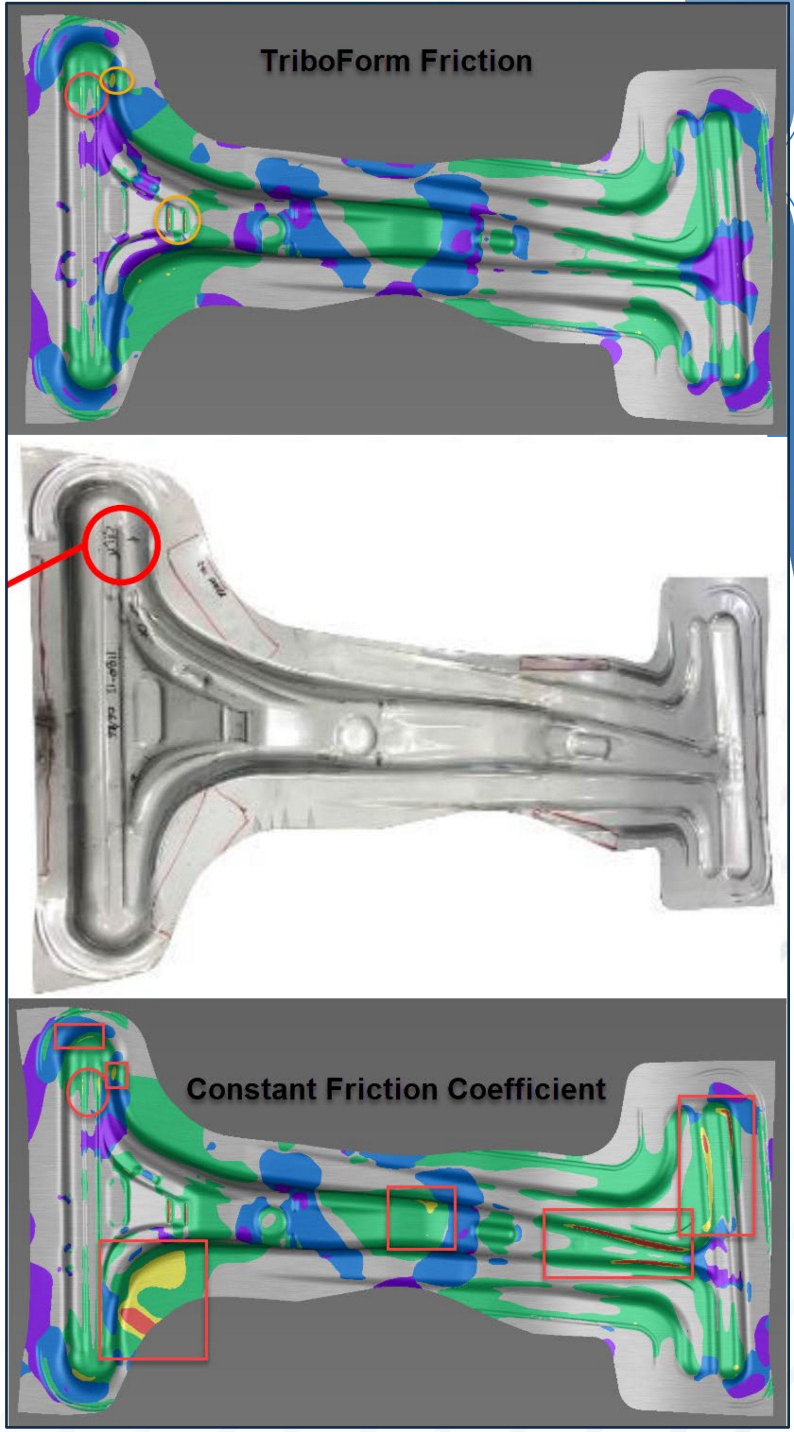
SIMULATION OUTCOMES 3RD GEN 1180

Draw Formability

- With TriboForm friction, nearly all false positives, generated with the constant coefficient determined from TCT, are eliminated

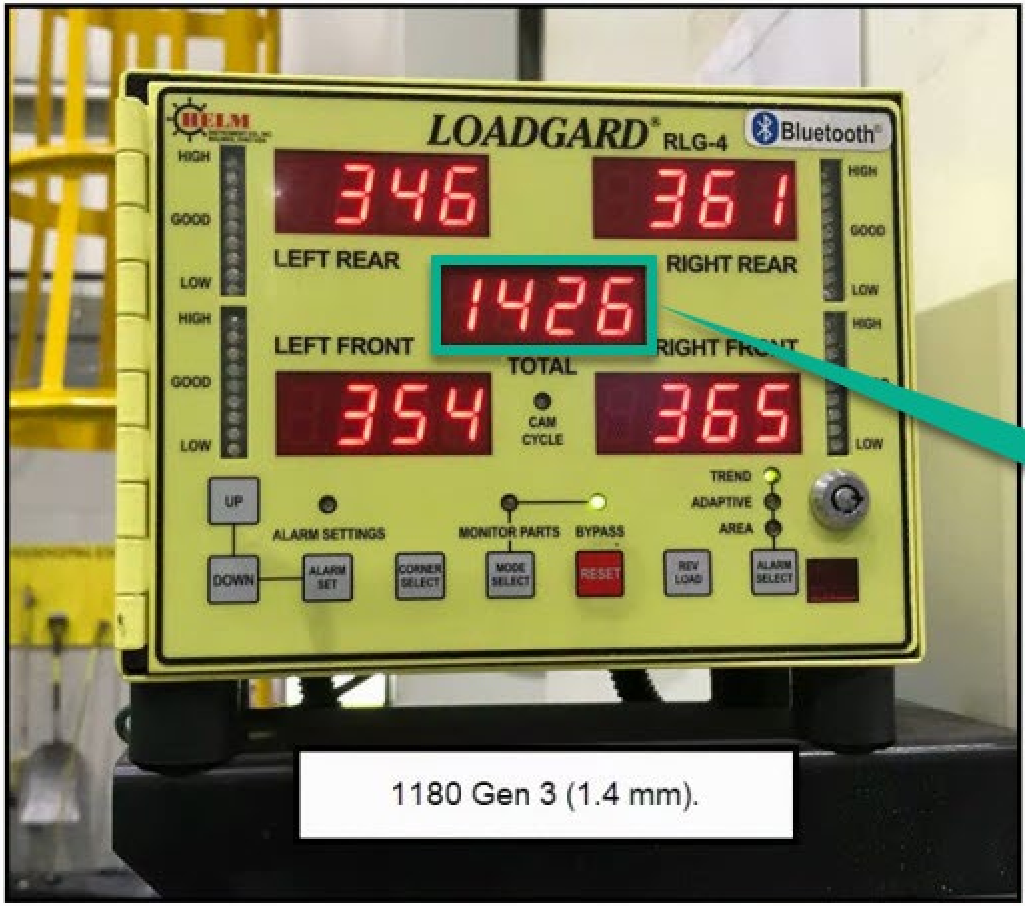
- Two locations show splitting / elevated risk

- These likely are due to the assumptions, made to cover unknown information, in the selection of the tribology systems



SIMULATION OUTCOMES 3RD GEN 1180

Draw Tonnage



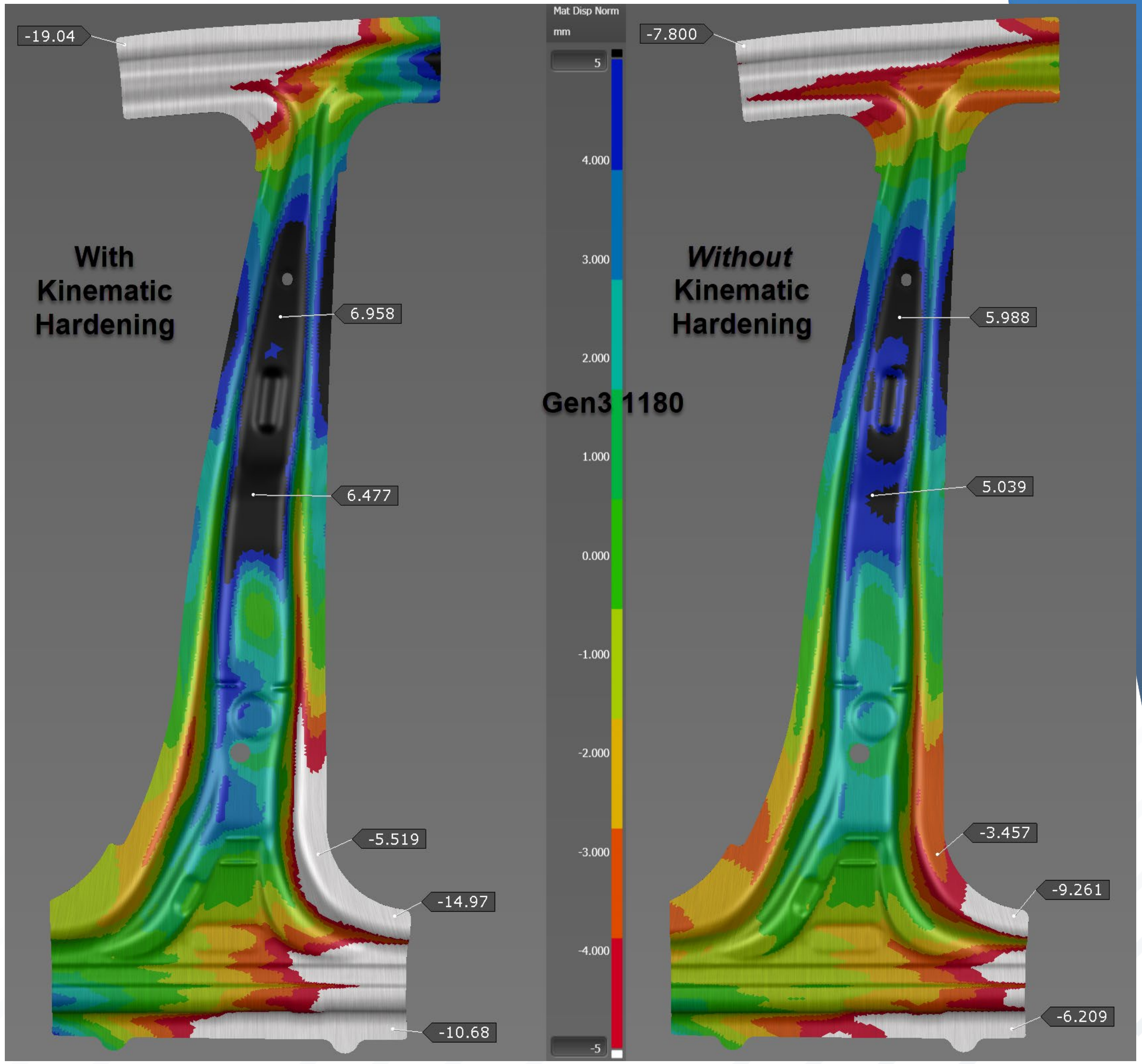
steel		USL -	UWL -	Max 1486.2 tonf
binder		USL -	UWL -	Max 399.0 tonf
post		USL -	UWL -	Max 1087.2 tonf

Predicted tonnage very close to tonnage recorded on the press

SIMULATION OUTCOMES
3RD GEN 1180

Total Springback:
With and without Kinematic Hardening

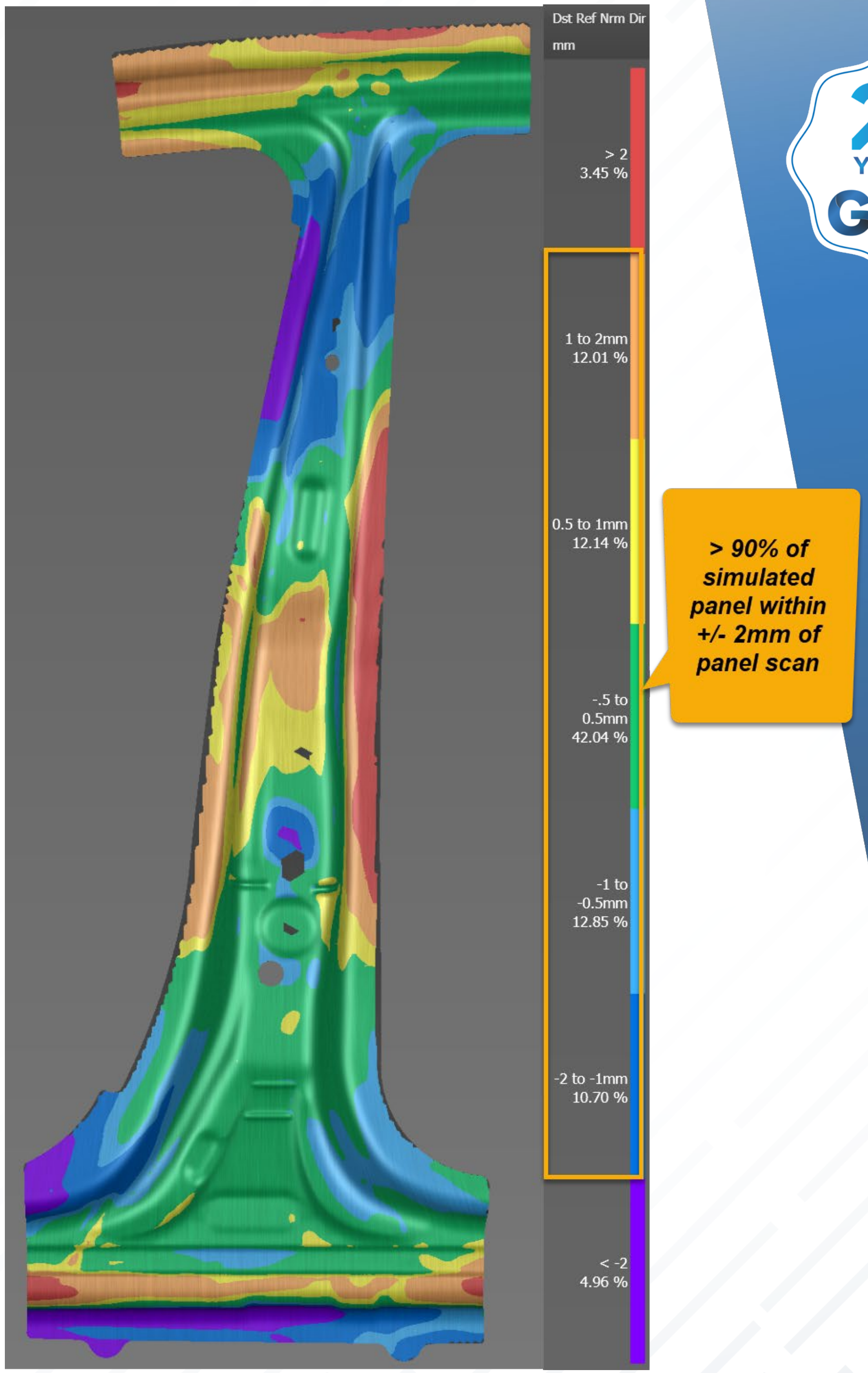
- Both cases show strong twist and flattening
- Springback magnitudes significantly higher with Kinematic Hardening
- Kinematic Hardening is an important factor in the springback response of panels, particularly AHSS



SIMULATION OUTCOMES 3RD GEN 1180

Best Fit to Scan of Sprung Panel:

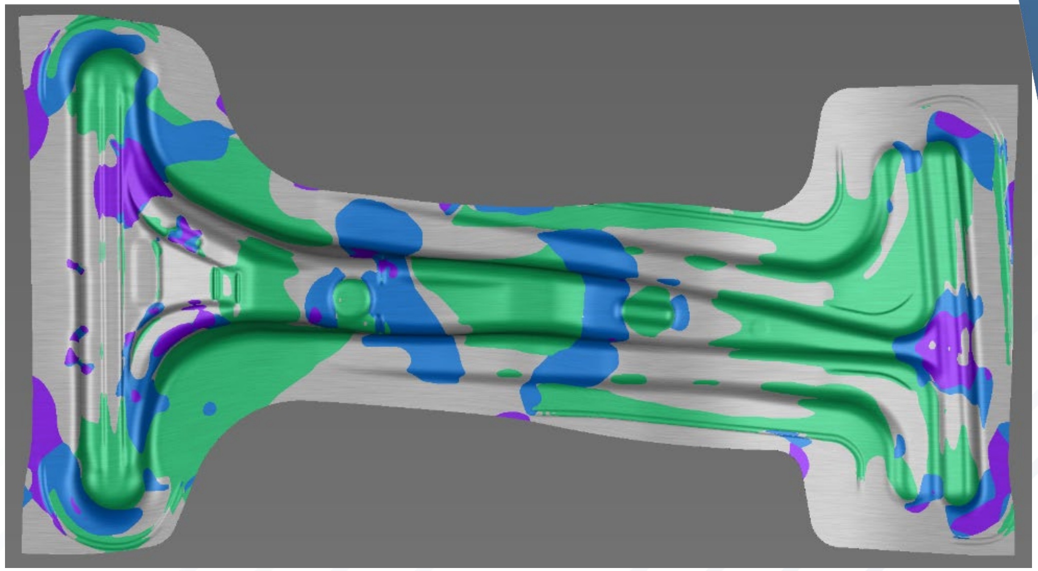
- Best Fit shows strong correlation between simulated sheet and scan of sprung panel



SIMULATION OUTCOMES 3RD GEN 980

Draw Formability

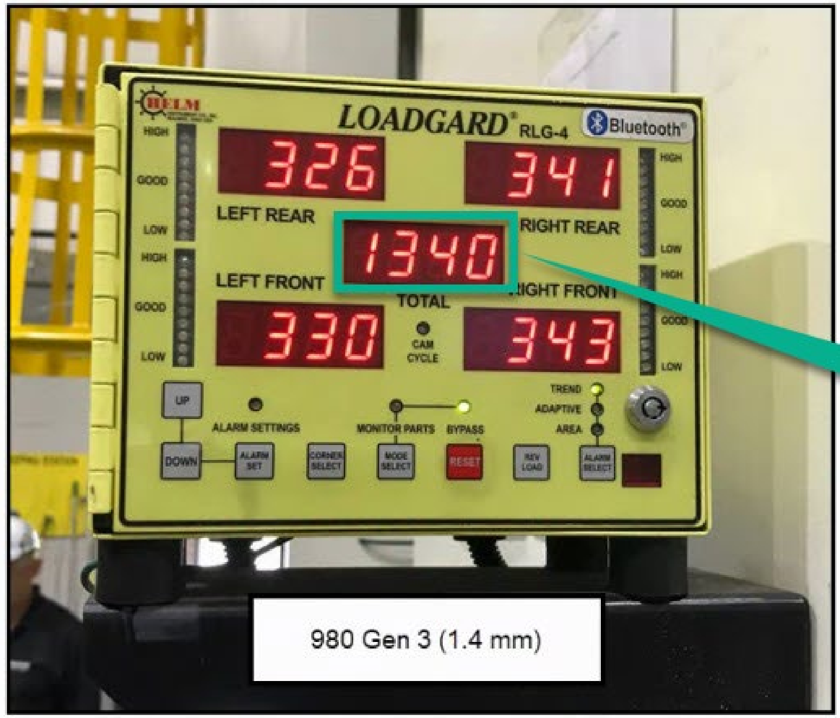
- No issues reported in tryout, and none predicted in simulation



SIMULATION OUTCOMES 3RD GEN 980

Draw Tonnage

- Predicted tonnage is about 8% below recorded



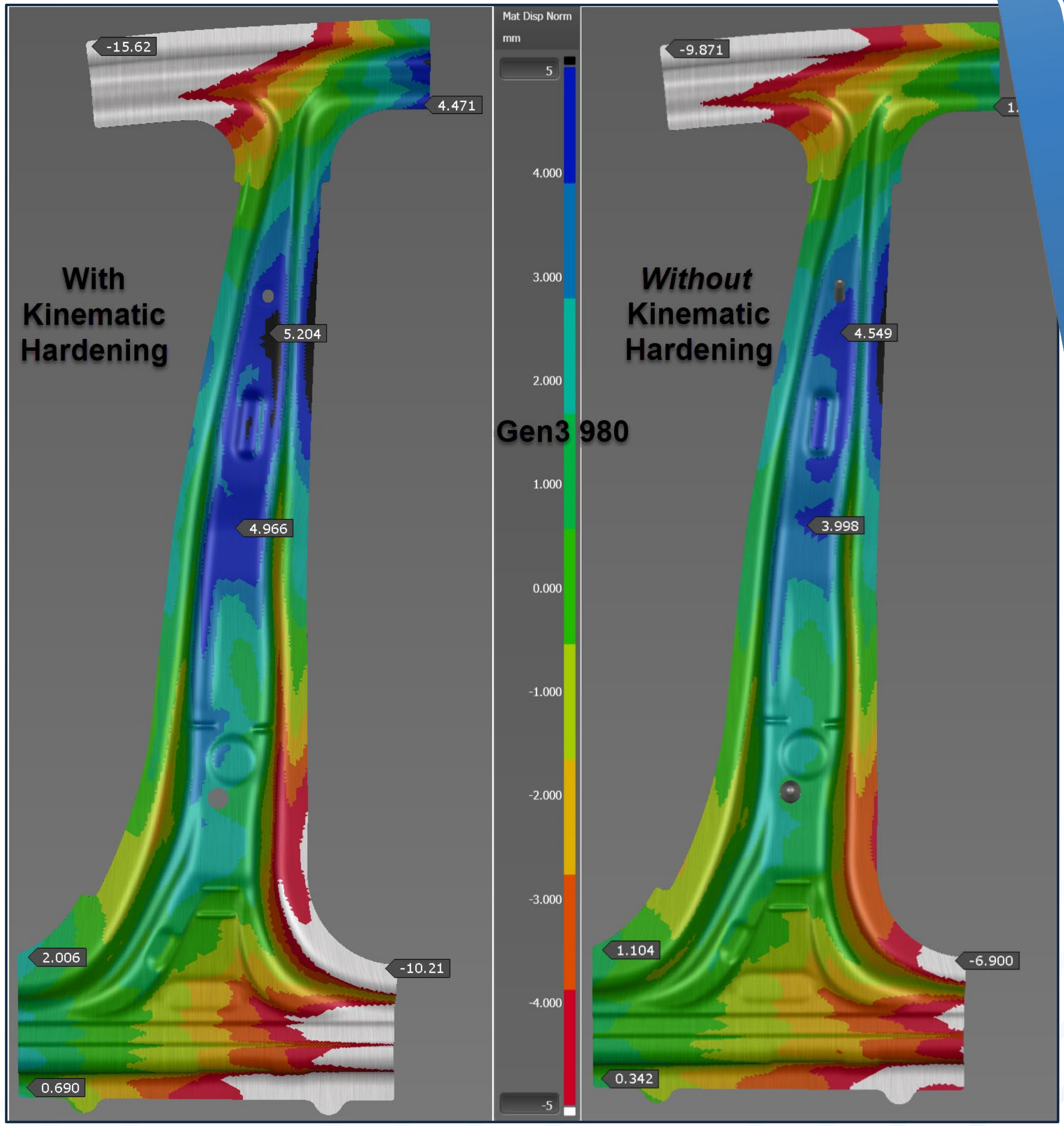
steel		USL -	UWL -	Max 1224.3 tonf
binder		USL -	UWL -	Max 399.0 tonf
post		USL -	UWL -	Max 825.3 tonf

Predicted tonnage close to tonnage recorded on the press

SIMULATION OUTCOMES
3RD GEN 980

Total Springback:
With and without Kinematic Hardening

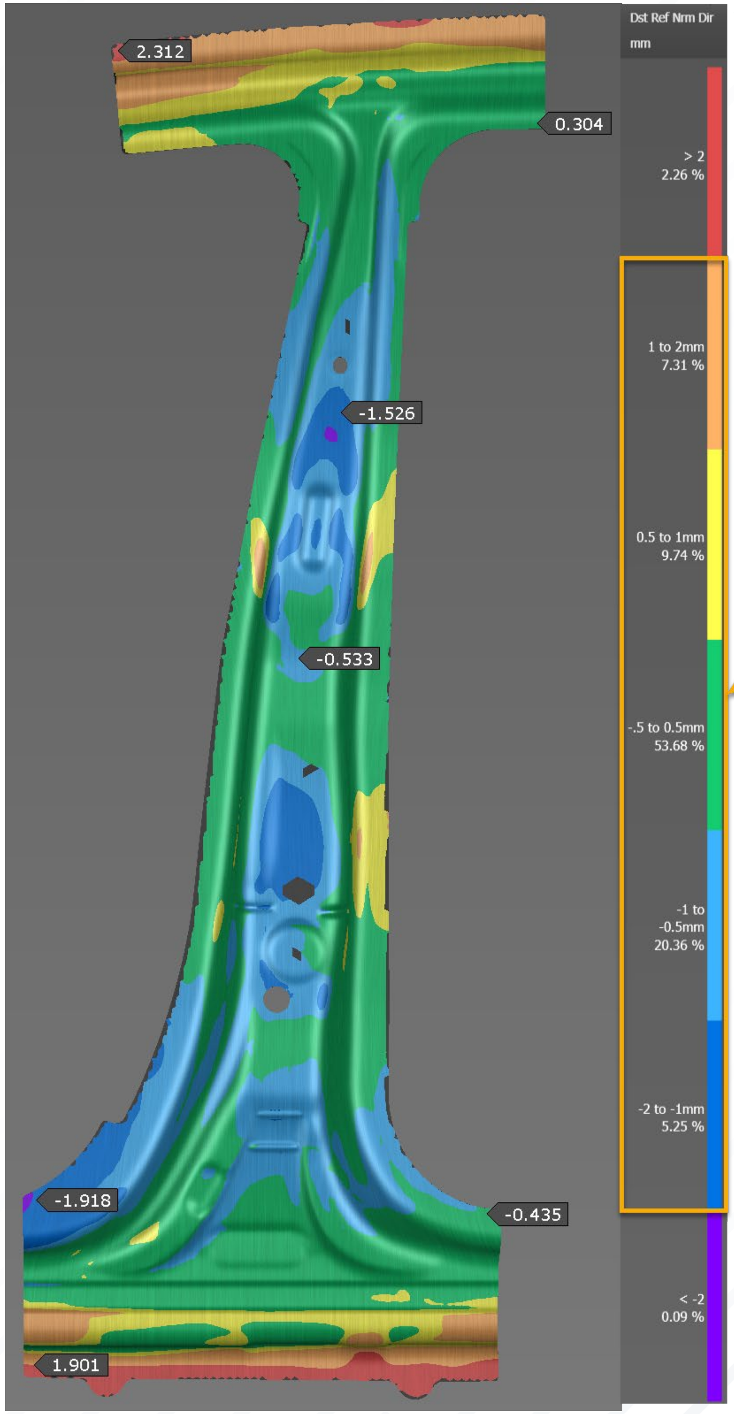
- Both cases show strong twist and flattening, although reduced relative to 3rd Gen 1180
- Springback magnitudes significantly higher with Kinematic Hardening
- Kinematic Hardening is an important factor in the springback response of panels, particularly AHSS



SIMULATION OUTCOMES 3RD GEN 980

Best Fit to Scan of Sprung Panel:

- Best Fit shows strong correlation between simulated sheet and scan of sprung panel



> 97% of simulated panel within +/- 2mm of panel scan

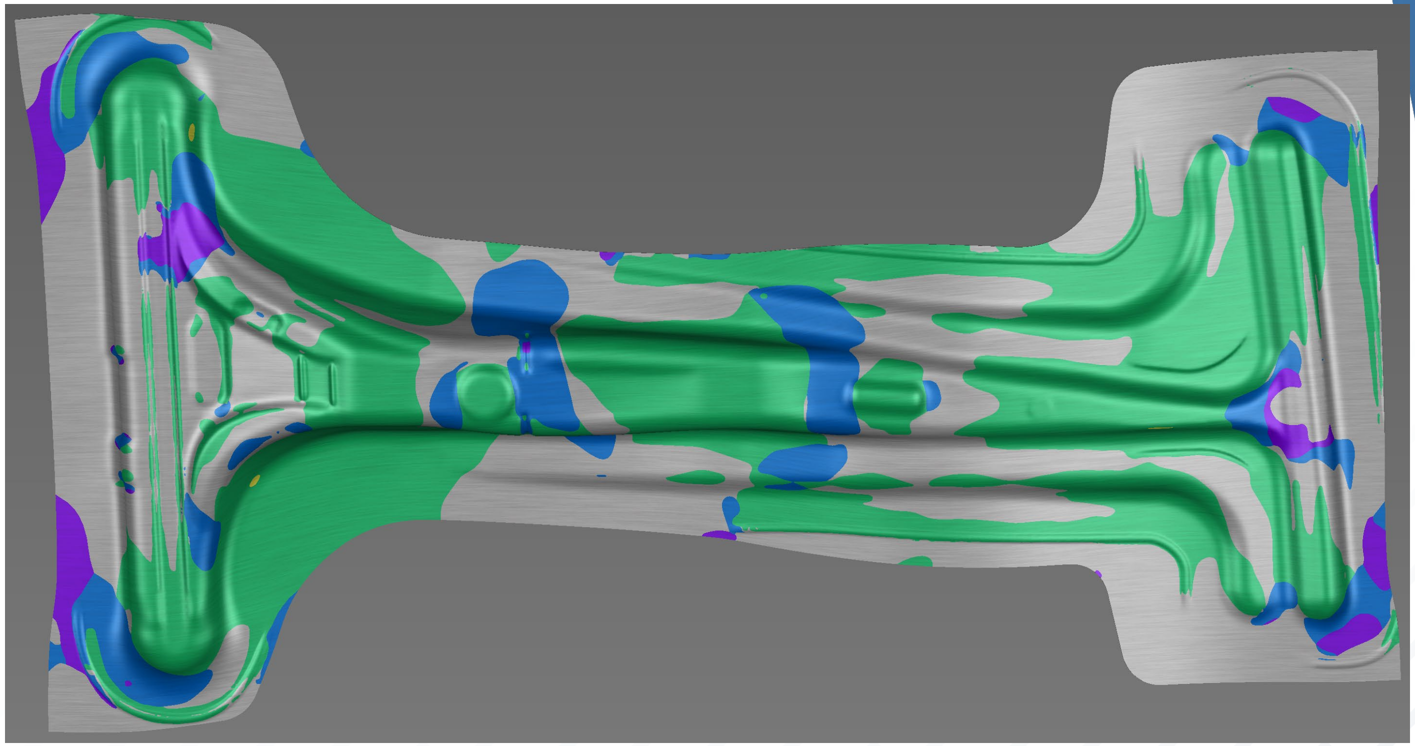
SIMULATION OUTCOMES
590R

Draw Formability

- No issues reported in tryout, and none predicted in simulation

Draw Tonnage

steel		USL -	UWL -	Max 1019.1 tonf
binder		USL -	UWL -	Max 399.0 tonf
post		USL -	UWL -	Max 620.1 tonf

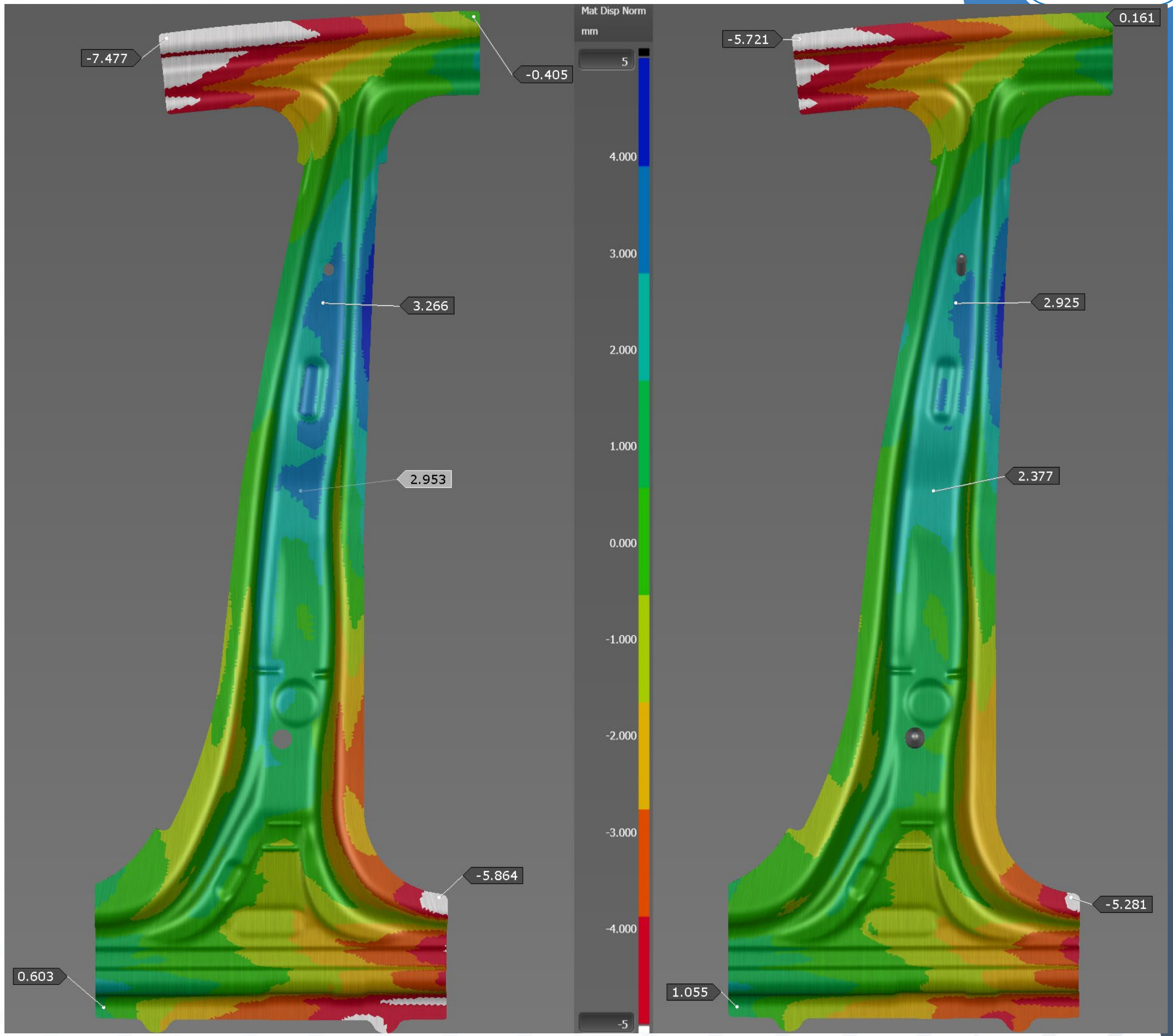


SIMULATION OUTCOMES 590R

Total Springback:
With and without Kinematic Hardening

- Reduced twist and flattening, relative to 3rd Gen 980 and 1180

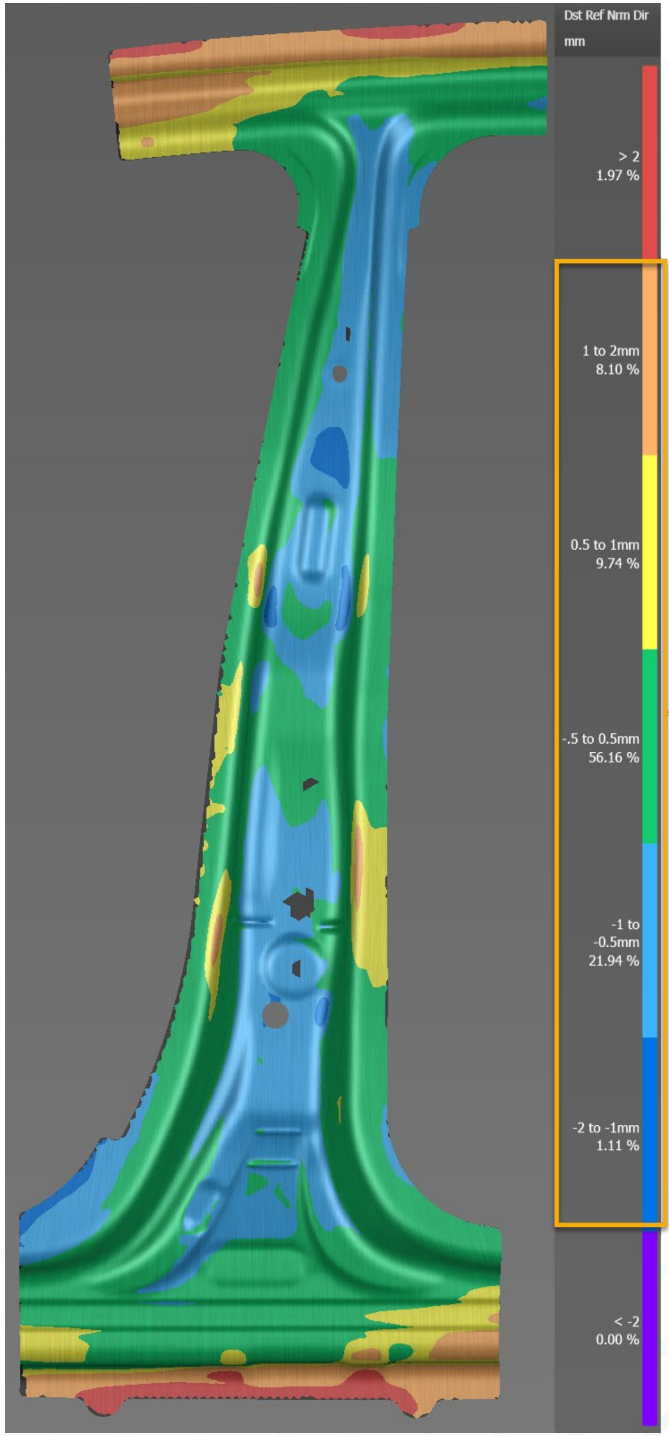
- Kinematic Hardening difference is not as pronounced as with the 3rd Gen grades



SIMULATION OUTCOMES 590R

Best Fit to Scan of Sprung Panel:

- Best Fit shows strong correlation between simulated sheet and scan of sprung panel



> 98% of simulated panel within +/- 2mm of panel scan

SUMMARY

- Available data and information – material, tribology, forming tools and process - afforded a *reasonably accurate* representation of the forming of b-pillar panels from AHSS blanks

- Formability, Tonnage, and Panel Springback outcomes from simulation are shown to correlate very well to physical observations for all the three blank materials formed

CONCLUSIONS

- Material modelling and tribology choices were driven by need, and *also by available data*

- The influence and therefore the *importance* of these choices upon all aspects of simulation outcomes is confirmed (again) from this study

- Of particular consequence to the prediction of panel springback for AHSS materials is the *characterization of kinematic hardening*

- Wide availability of kinematic hardening data, directly from material suppliers, is *crucial* to engineering and manufacture of products with AHSS, and 3rd Gen (and future) grades

ACKNOWLEDGEMENTS

UNIVERSITY OF WATERLOO

BOWMAN PRECISION TOOLING

HONDA The Power of Dreams

American Iron and Steel Institute

CLIFFS

ArcelorMittal

NUCOR®

FOR MORE INFORMATION

Kanaan Kidambi
AutoForm
Kidambi.kannan@autoform.com

Jamie Bowman
Bowman Precision Tooling
jamie@jpbowmantool.com

Cliff Butcher
University of Waterloo
cbutcher@uwaterloo.ca

Cameron O’Keefe
Honda - HDMA
cokeefe@na.honda.com