Advancing Understanding in Forming and Fracture in 3rd GEN Steels

BRIAN LIN

SRIRAM SADAGOPAN

ArcelorMittal
GLOBAL RESEARCH AND DEVELOPMENT CENTER
EAST CHICAGO INDIANA

GREAT DESIGNS IN STEEL™

OUTLINE

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Introduction

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- Quenched & Partitioned steels (Q&P) or Gen. 3 AHSS offer a strong combination of strength and ductility in cold-stamped automotive steels
- Retained austenite (RA) in the microstructure enhances the work hardenability through the transformation of austenite to martensite during deformation (the TRIP effect)
- In literature, the TRIP effect is primarily examined in tension only
- However, from a forming perspective, industrial stamping will typically include different strain paths, which may result in differences in austenite to martensite transformation
- And from a crash perspective, the residual ductility in the material is also an important attribute to consider when wholistically evaluating the material performance

Objective

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The nature of the transformed martensite and interaction with the other phases in the microstructure will play an important role in post-forming ductility.

The aims of this study are to:

- Characterize the retained austenite transformation of Q&P steels as a function of strain, and strain path to replicate industrial stamping conditions
- Determine the post-forming fracture behavior replicating material behavior under crash load cases

Materials and Methodology
GEN 3 AHSS studied

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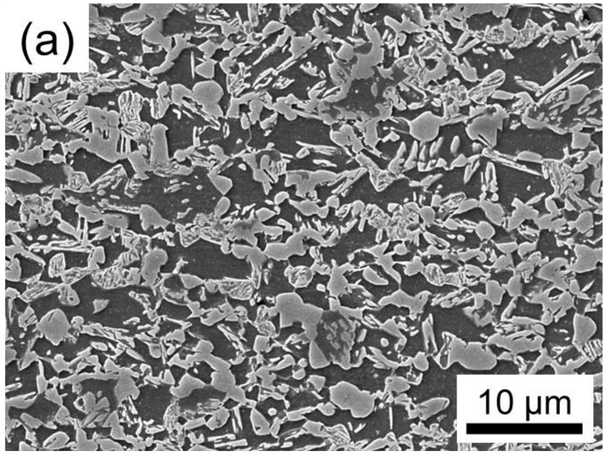
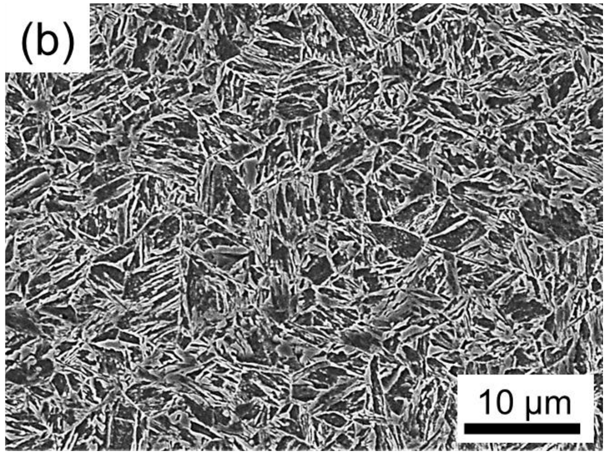
Two industrially produced Gen. 3 AHSS were studied with galvanized (GI) coating

GI Fortiform®980

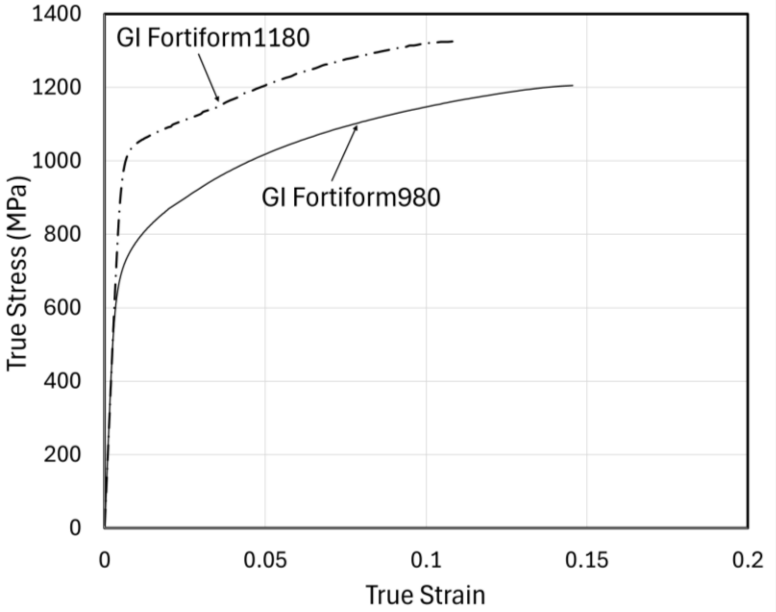


Ferrite containing Q&P steel

GI Fortiform®1180



Non-ferrite containing Q&P steel



Steel Name	YS (MPa)	TS (MPa)	TE (%)	Min. R/t
GI Fortiform®980	660	1020	22	<1.0
GI Fortiform®1180	1030	1210	16	<1.0

Materials and Methodology
GEN 3 AHSS studied

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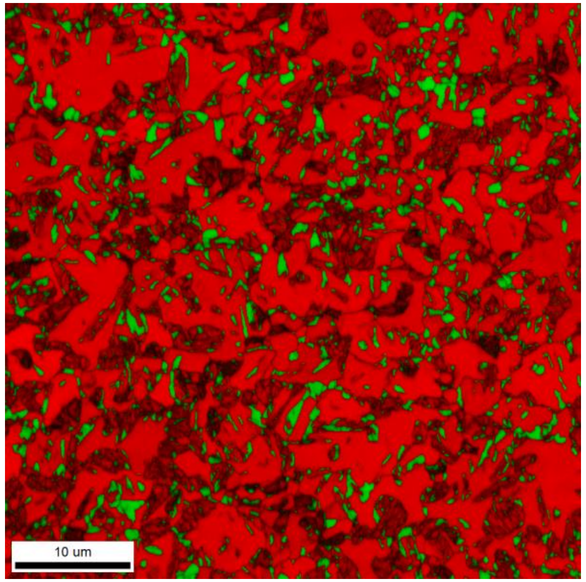
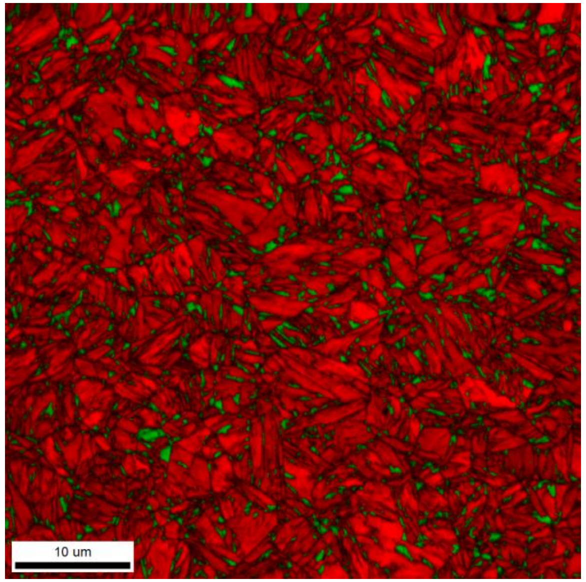
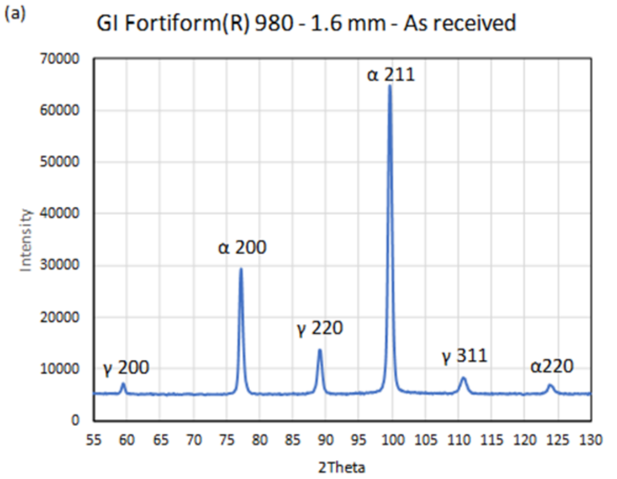
Two industrially produced Gen. 3 AHSS were studied with galvanized (GI) coating

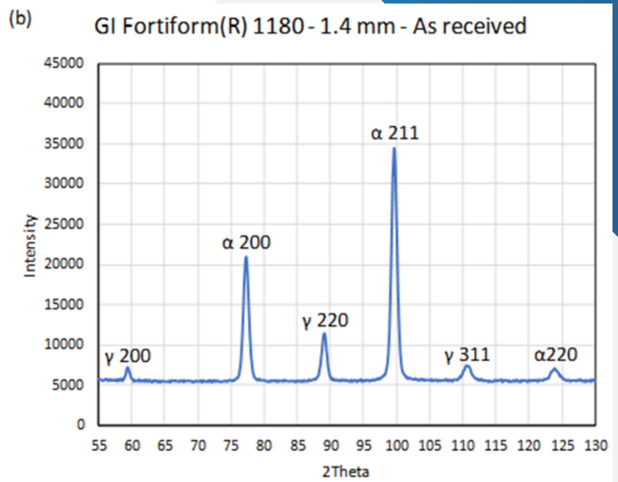


GI Fortiform® 980
EBSD IQ + Phase Map



GI Fortiform® 1180
EBSD IQ + Phase Map





Steel Name	Ferrite	Retained Austenite (EBSD)	Retained Austenite (XRD)	Bainite + Tempered Martensite + Fresh Martensite
GI Fortiform®980	40%	11%	15%	Bal.
GI Fortiform®1180	< 1%	10%	14%	Bal.

Materials and Methodology
Prestraining Samples

Biaxial prestrains were introduced using a Marciniak tooling (to simulate forming)

Strain paths (balanced biaxial and plane strain) changed by changing sample dimension

The magnitude of prestrain changed by increasing the forming depth

- Three levels of prestrain studied for each strain path

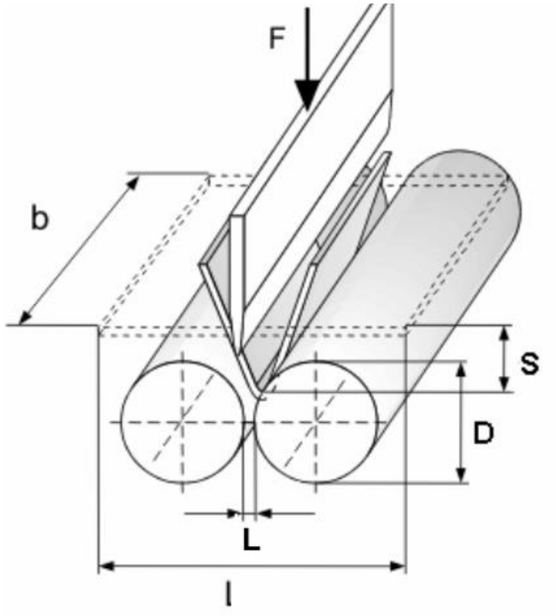
Balanced biaxial

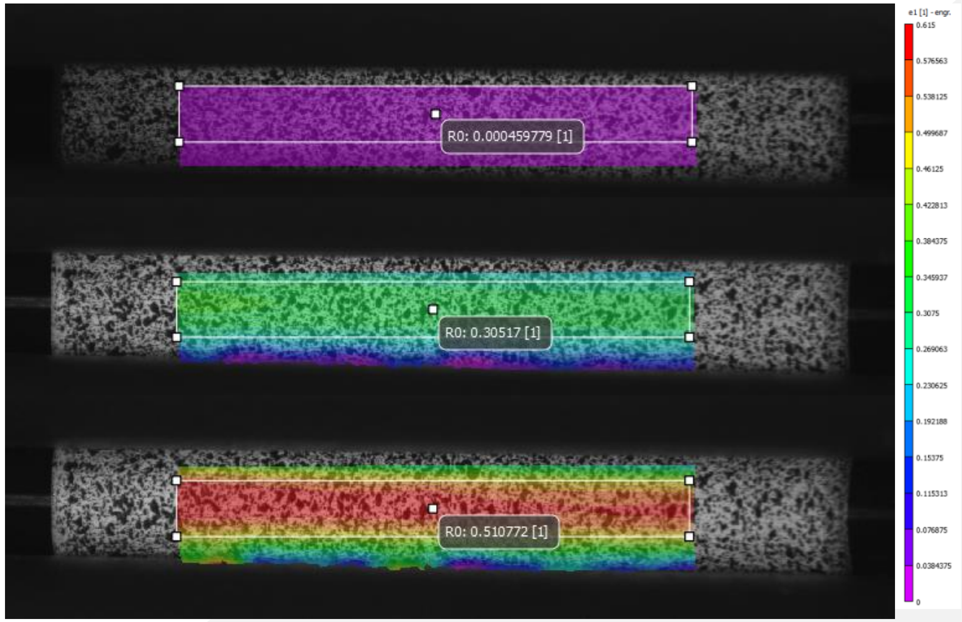
Plane strain

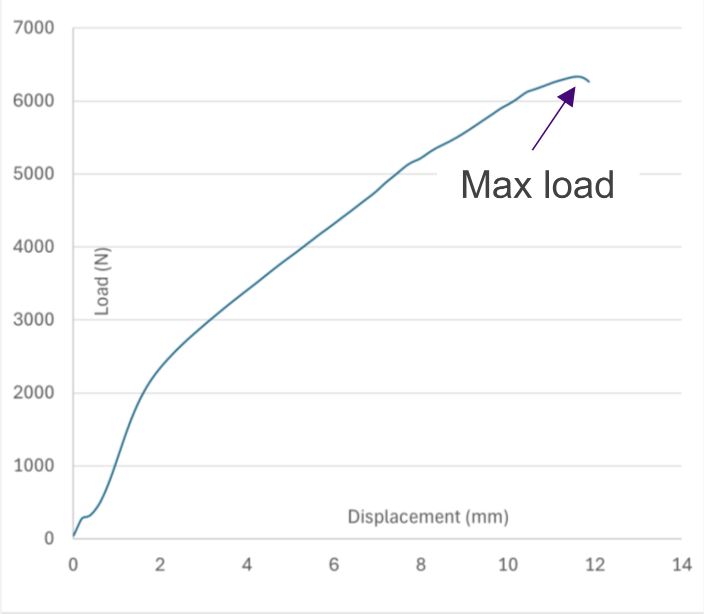
Materials and Methodology
Post Forming Properties

Samples extracted from prestrained samples for post-forming fracture strains and retained austenite (RA) measurements

Local fracture strain measured by VDA238-100 bend test equipped with digital image correlation (DIC) to determine the major and minor strain on the tension side of the bend specimen (axis along the rolling direction)



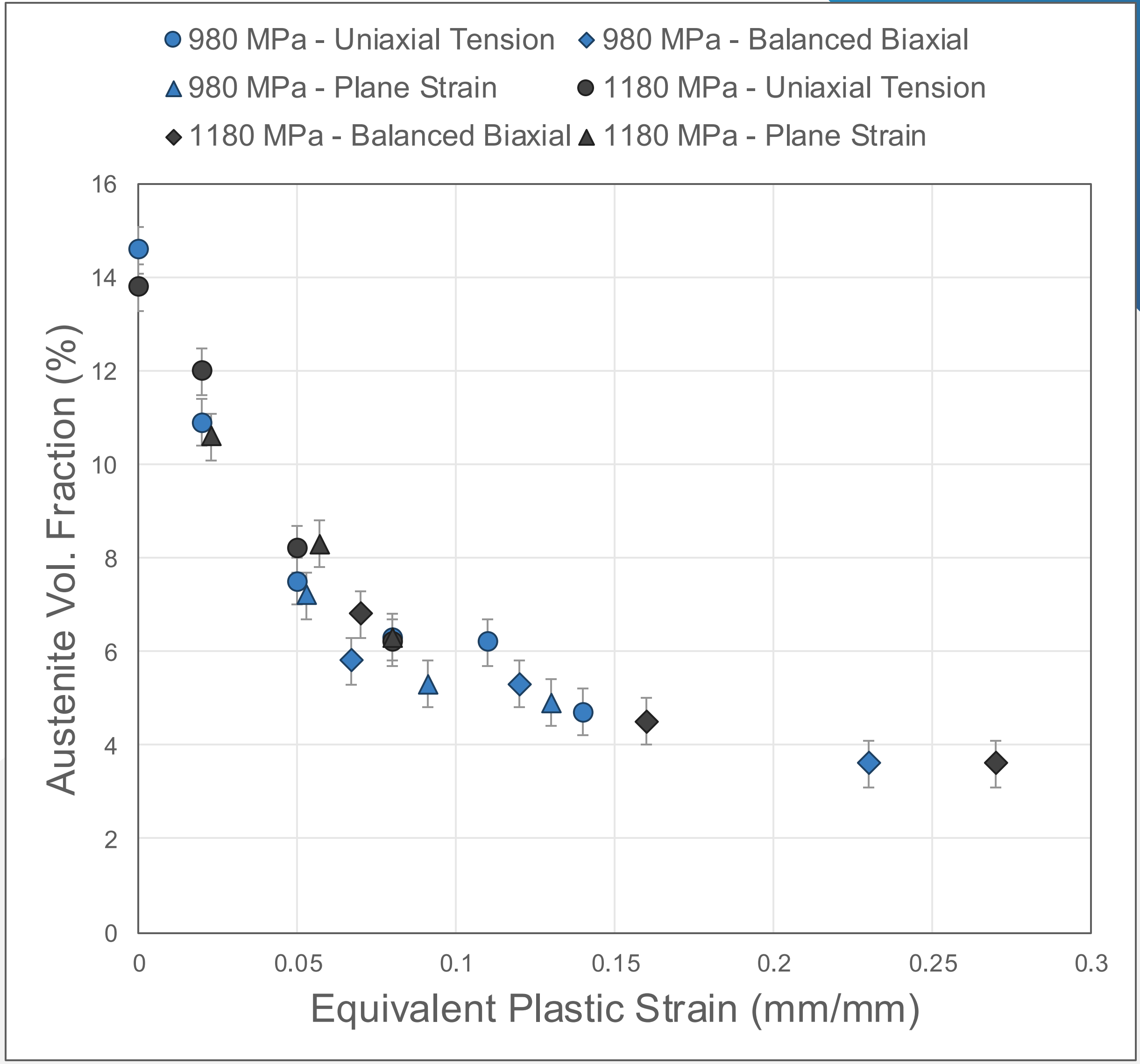




Experimental Results
Retained Austenite Evolution

Similar starting RA volume fraction (~14%) between Fortiform® 980 and 1180 steels

- RA volume fraction decreases with prestrain
- Caused by transformation of RA to martensite with increasing prestrain
- The decrease is higher in the initial stages of prestraining followed by saturation at higher strains
- **Preservation of some RA for post-forming ductility**
- Relatively minor effect of strain path



Experimental Results
Post Forming Ductility

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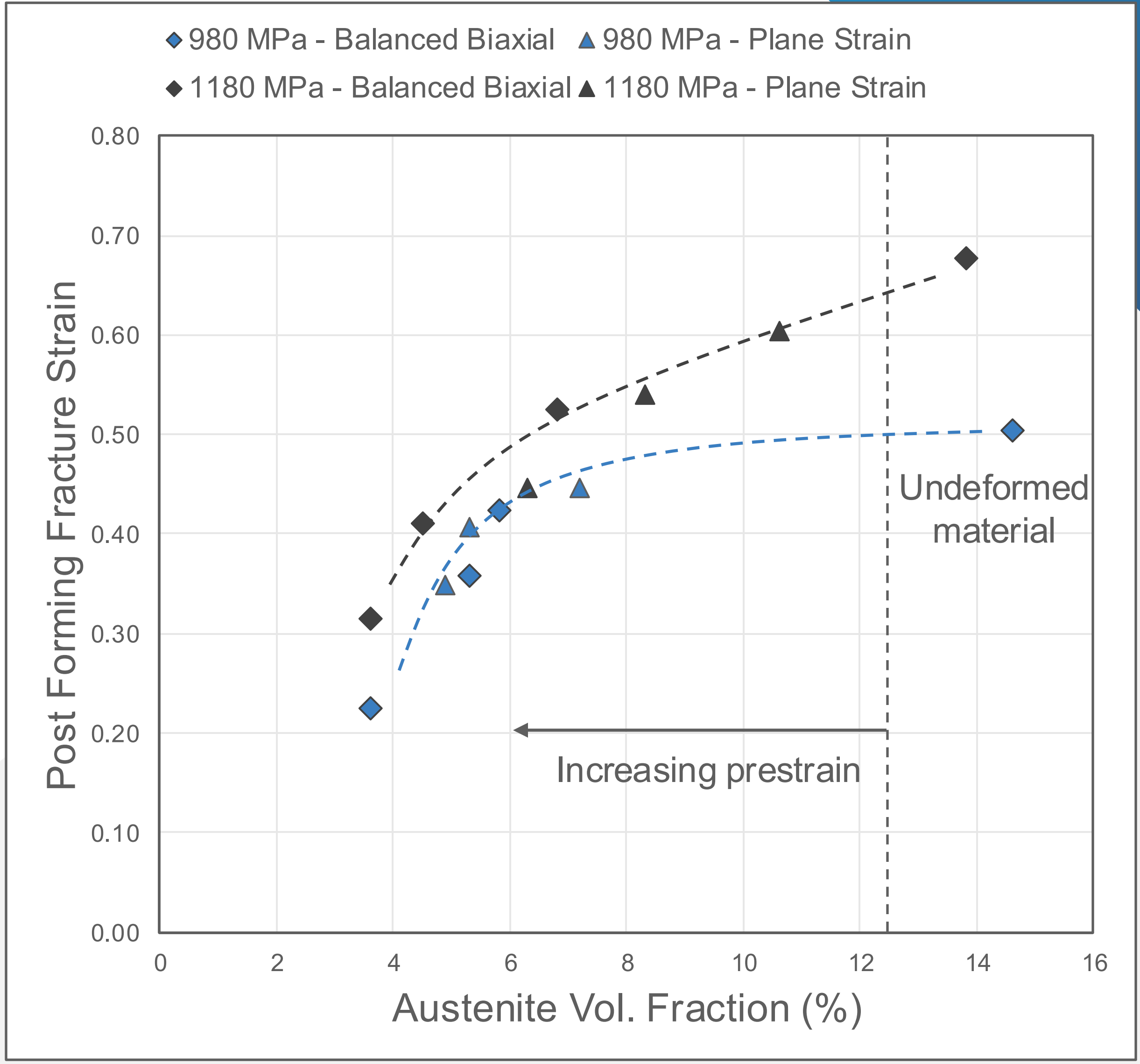
Higher fracture strain in the as-received state for Fortiform® 1180 as compared to 980 because of a more refined and uniform microstructure

Post forming ductility decreases with increasing bi-axial prestrain magnitude

- Fortiform® 1180 shows a bigger drop in post forming ductility in the inital stages as compared to Fortiform® 980 steel

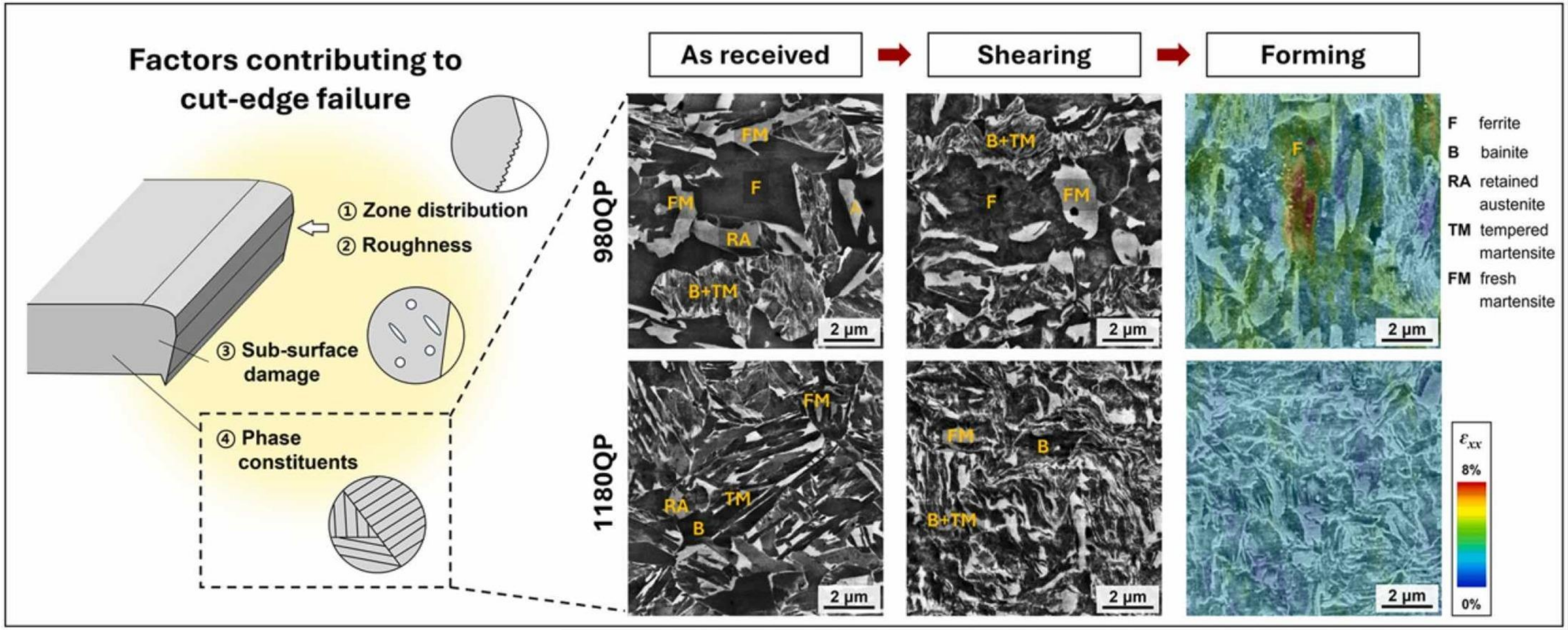
Needs to be understood further…



Experimental Results
Post Forming Ductility Discussion

In related work (on cut-edge ductility) with MIT supported by ArcelorMittal

- Early damage linked to strain localization in soft, low strain hardening phases
- Uniform deformation of phases improves resistance to edge cracking



Kim, Kyung-Shik, et al. "Understanding cutting-induced reduction in sheet metal formability: An in-situ investigation of microstructural effects." Journal of Materials Processing Technology 341 (2025): 118894.

Discussion
Post-Forming Fracture Strain and Cut-edge Ductility

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In GI Fortiform®980…

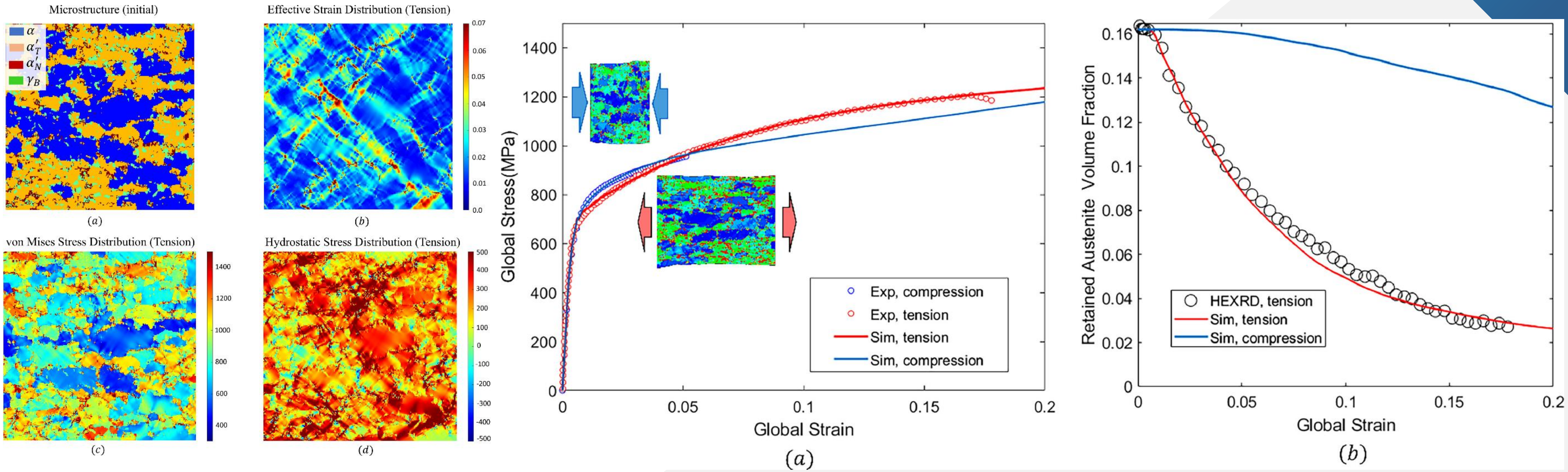
- Initial fracture strain is low and decreases slightly with some increasing pre-strain
- Cut-edge ductility is also low as strain localization occurs between soft (ferrite) phases and low strain hardening phases (fresh martensite)
- These microstructure features are already present in the starting microstructure as the initial damage nucleation sites; and the transformation of retained austenite to new fresh martensite does not introduce more sites that contribute to nucleation (but can assist in propagation)

In contrast, in GI Fortiform®1180…

- Initial fracture strain is high and decreases with increasing pre-strain
- Cut-edge ductility is also high as deformation of phases with uniform hardness (no soft phase ferrite) improves resistance to edge cracking
- The transformation of retained austenite to fresh martensite DOES introduce new damage nucleation sites between the transformed austenite and the matrix
- The decrease in fracture strain with decreasing retained austenite content is due to the increased number of damage nucleation sites with transformations

On-going and future work
Development of a Crystal Plasticity Model

In collaboration with Oak Ridge National Lab (ORNL) supported by the DOE, a crystal plasticity model was developed to account for the transformation induced plasticity (TRIP) effect and verified



Cheng, Jiahao, et al. "A mesoscale crystal plasticity model to predict room-temperature deformation and martensitic transformation of high-strength Quenching and Partitioning (Q&P) Steels and validation with synchrotron X-ray diffraction." *International Journal of Plasticity* 172 (2024): 103833.

On-going and future work
Extending CP to a Reduced Order Model

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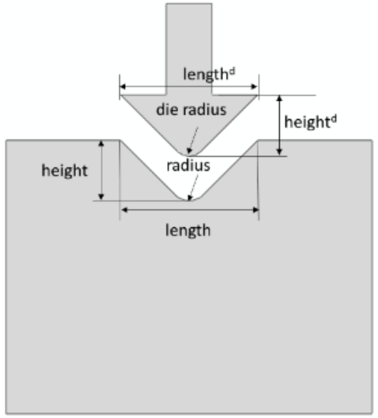
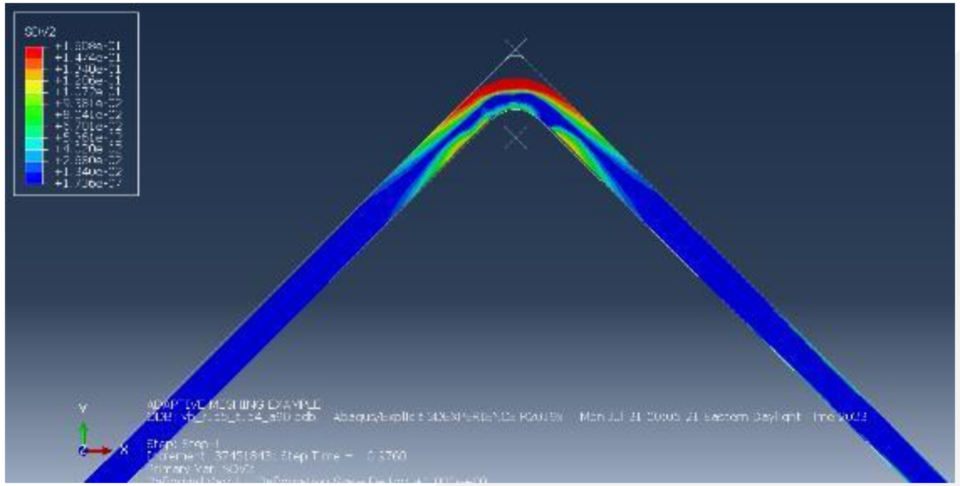
In collaboration with ORNL, the crystal plasticity model is being extended to a reduced order surrogate model to simulate “large” parts

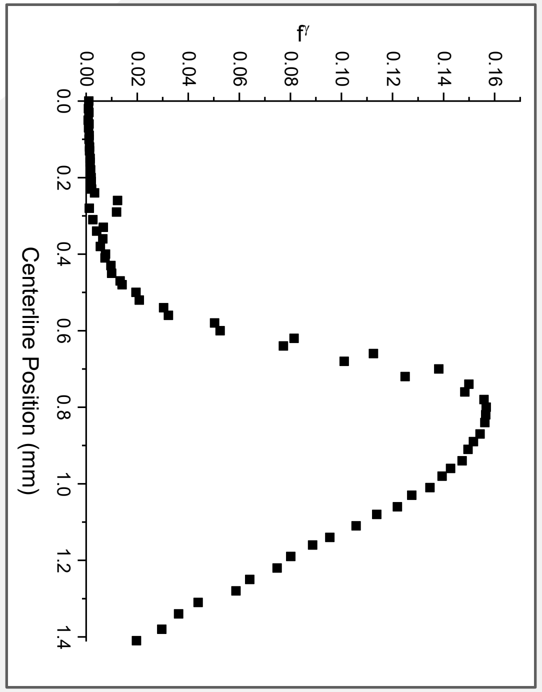
Initial work on a bending simulation indicate an asymmetry in austenite transformation about a bend axis (greater in tension than in compression)

End goal is to extend these simulations further to consider fracture



List of dimensions in mm:
Height =see next page
Length =49.5
Radius = see next page
Die radius =varied 0.5 - 10.0mm
Length^d = 50
Height^d = 25





Hu, Xiaohua, et al. "Prediction of the influence of strain magnitude and strain path on the resulting microstructure and post-forming mechanical behavior of RA containing high formability steels." , Dec. 2023. https://doi.org/10.2172/2229232

CONCLUSIONS

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The post forming fracture behavior of Gen. 3 AHSS was evaluated using a combination of in-plane stretching and DIC-assisted VDA bend testing

In the two Fortiform® steels studied, the results showed with increasing prestrain:

1. A decrease in post-forming RA volume fraction
2. And a decrease in the post-forming fracture strain

A negligible influence of in-plane stretching strain paths on RA volume fraction was observed

However, the reduction of post-forming fracture strain was not identical between these two steels

This difference likely arises due to the influence of the different starting microstructures and how damage initiation differs between these two steels – to which crystal plasticity simulations are being performed at the microstructural level to validate this idea

Acknowledgments and thank you for your attention

Narayan Pottore
ArcelorMittal

Hong Zhu
ArcelorMittal

Xiaohua Hu
(Formerly ORNL)

Subrato Sarkar
ORNL

Su Liu
ArcelorMittal

Gang Huang
ArcelorMittal

Jiahao Cheng
(Formerly ORNL)

Jason Mayeur
ORNL

For questions and more information

Brian Lin
ArcelorMittal
brian.lin@arcelormittal.com

Sriram Sadagopan
ArcelorMittal
Sriram.sadagopan@arcelormittal.com

Steels for cold stamping - Fortiform®

https://automotive.arcelormittal.com/products/flat/third_gen_AHSS/fortiform