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Enhancing Sheared Edge Stretchability of AHSS/UHSS

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PACIFIC NORTHWEST NATIONAL LABORATORY
RICHLAND, WA, USA

PROJECT ID# LM106

Overview

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Timeline

- Project start date: FY15
- Project end date: FY18
- Percent complete: 30%

Budget

- Total project funding
  - DOE share: $1,800k
  - Industry in-kind: $1,200k
- Funding received in FY 2015:
  - DOE: $400k
  - In-kind: $300k
- Funding for FY 2016:
  - DOE: $400k
  - In-kind: $300k

Barriers

- Edge stretchability is a key barrier for the increasing application of AHSS/UHSS into vehicle structures for weight reduction and crash performances
- Edge stretchability is highly influenced by a number of factors including material microstructures, blank preparation processes, die wear, and edge loading conditions.
- Lack of a quantitative and predictive understanding linking microstructural characteristics to edge stretchability under different conditions.

Partners

- Oakland Univ: SF Golovashchenko
- Ford: C Chiriac, R Sohmshetty
- US Steel: B Hance, MF Shi
- AK Steel: KS Raghavan, YW Wang

AHSS/UHSS Edge Preparation and Stretchability

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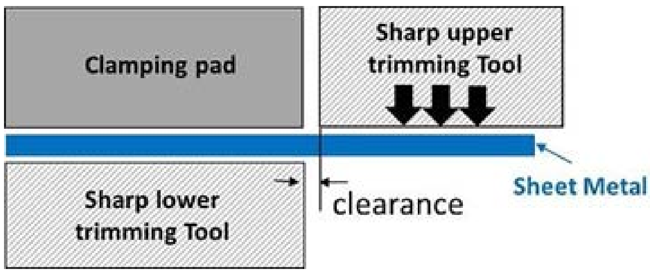
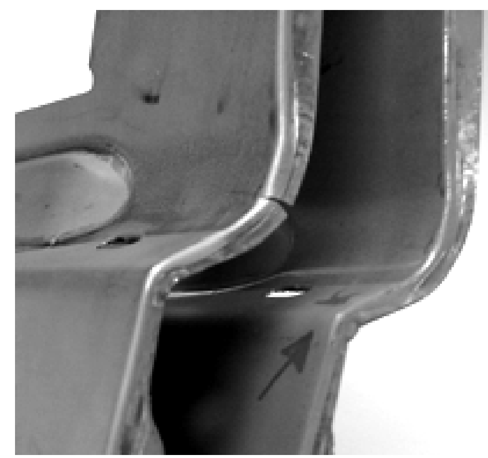


- Edge stretchability of AHSS is grade- and microstructure- dependent.
- Same grade AHSS from different producers can have quite different local formabilities, i.e., stretchability and hole expansion ratio.
- Trimmed surface quality is very sensitive to the alignment accuracy of the upper and lower dies.
- Burrs and edge damages are typical defects encountered in trimming.
- Insufficient die stiffness poses a problem due to the increased trimming forces necessary for AHSS steel.
- Tooling alignment is especially difficult in curved areas of the trim line.



Examples of edge fractures in AHSS stamped parts

Relevance and Project Objectives

- Enhance the sheared edge stretchability of AHSS/UHSS by
  - Developing quantitative and predictive understanding of the role of microstructure on sheared edge fracture and stretchability
  - Building validated predictive capabilities to quantify relationships between microstructures and trimming condition to trimmed edge quality and to subsequent stretchability:
- Accelerate the development of next generation advanced high strength steels (steel companies) and enable a rapid and cost-effective deployment of AHSS/UHSS in vehicle structures (auto OEMs) for substantial mass savings that will result in vehicle lightweighting to reduce greenhouse gas emissions and dependency on foreign oil

Milestones and Go/No Go Decision Points

- SMART goal – Complete macroscopic shearing/piercing process simulation with experimental validation – Regular goal, and estimated completion date: 9/30/2015. ✓ 12/31/2015 (actual)
- Three quarterly progress measurement goals
  - 12/31/2014: Regular goal: Acquire materials and complete literature review on different DP980 hardening behaviors
  - 3/31/2015: Regular goal: Complete experimental characterizations of micro- and macro-scopic properties of DP980
  - 6/30/2015: Regular goal: Complete shearing/piercing experiments on two DP980 steels with different clearances
- Go/No-go decisions– Predicted burr geometry >90% accurate for different DP980 under different clearances ✓

Technical Approaches

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- Task 1. Literature review on DP980 hardening behaviors and software capability analysis (PNNL, Ford, OU, USS and AK)
- Task 2. Collect materials and perform macro- and micro- material property characterization (OU, USS, AK, Ford and PNNL)
- Task 3. Macroscopic Shearing/Piercing process simulations (macro-models) and experimental validation (PNNL, Ford, OU, USS and AK)
- Task 4. Microscopic damage characterization and prediction at SAZ (PNNL)
- Task 5. Macroscopic fracture and stretchability prediction with experimental validation (PNNL, OU, USS and AK).
- Task 6. Develop optimized process parameters and microstructures for sheared edge stretchability (PNNL, OU, USS, AK and Ford)

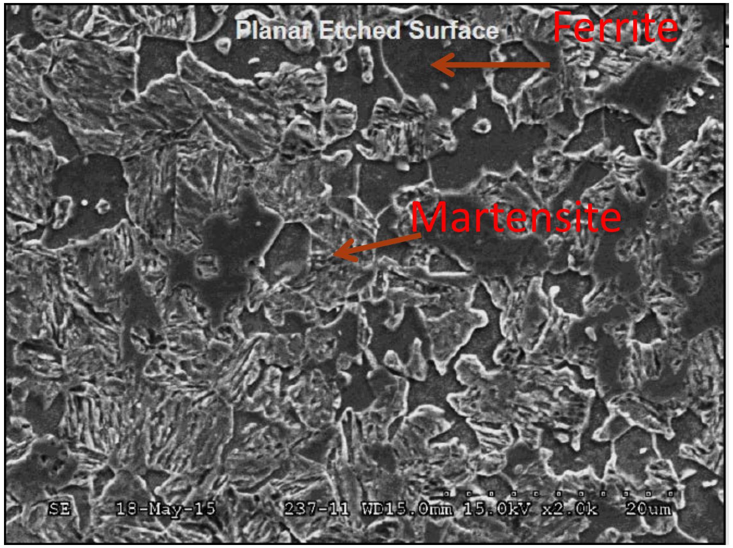
Progress Summary:
Task 2: Materials and macro- & micro- characterizations

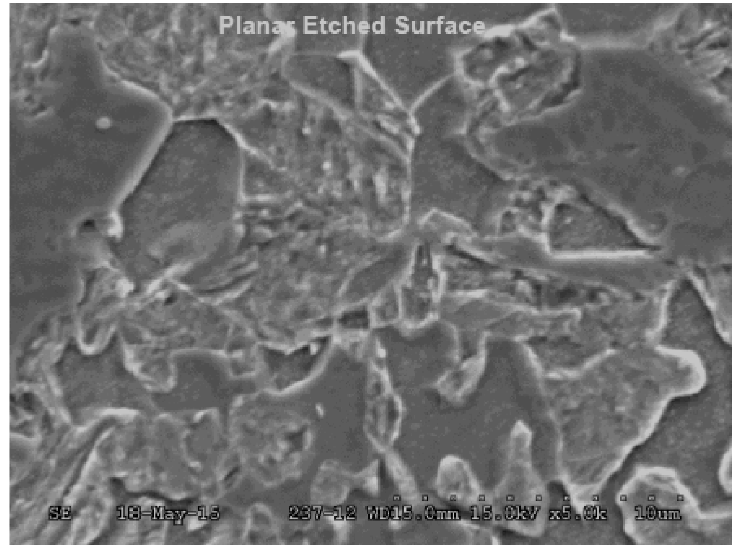
- Two DP980 steels (1 & 2) were provided by steel companies
- Microstructures were characterized and tensile test were performed by the steel companies
- Accumulated rolling were conducted on both steels and subsequent tensile tests were performed on rolled sheets of DP980-2 for different reductions to obtain flow behaviors at large strains.
- In-situ HEXRD tensile tests were performed to obtain initial texture and lattice strains of two steels where are used to find individual phase properties aided with EPSC modeling.

Task 2: Microstructure characterization

x2000

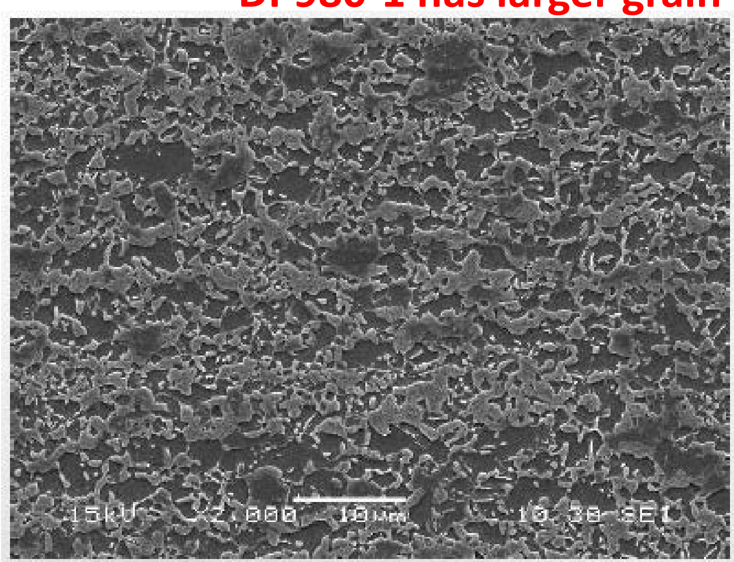
x5000

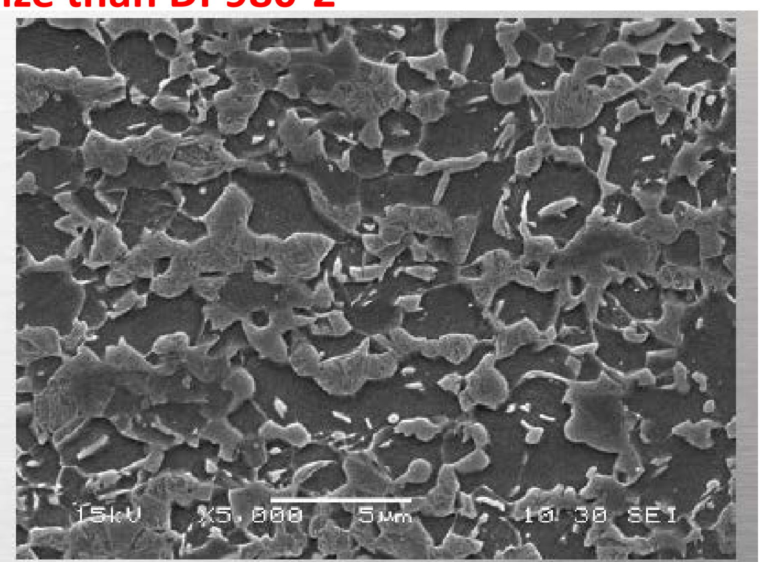




DP980-1

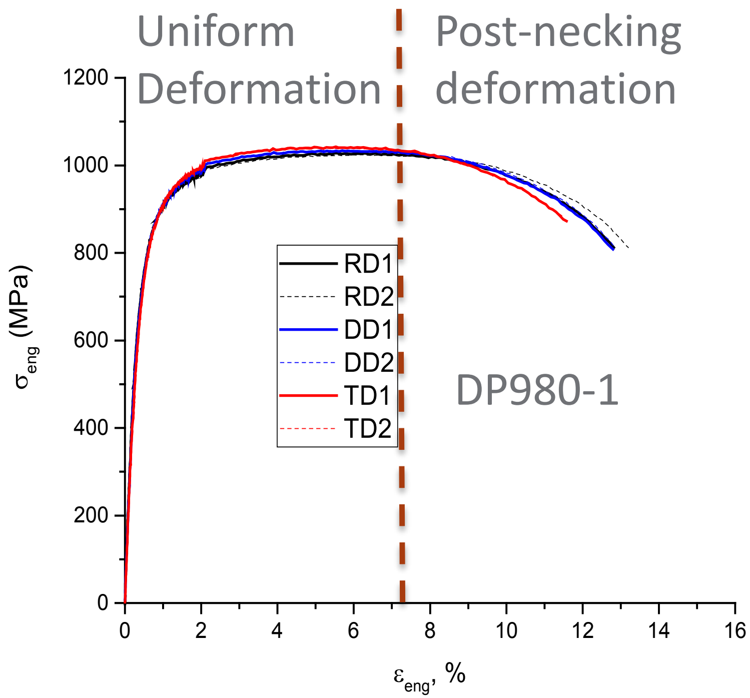
DP980-1 has larger grain size than DP980-2

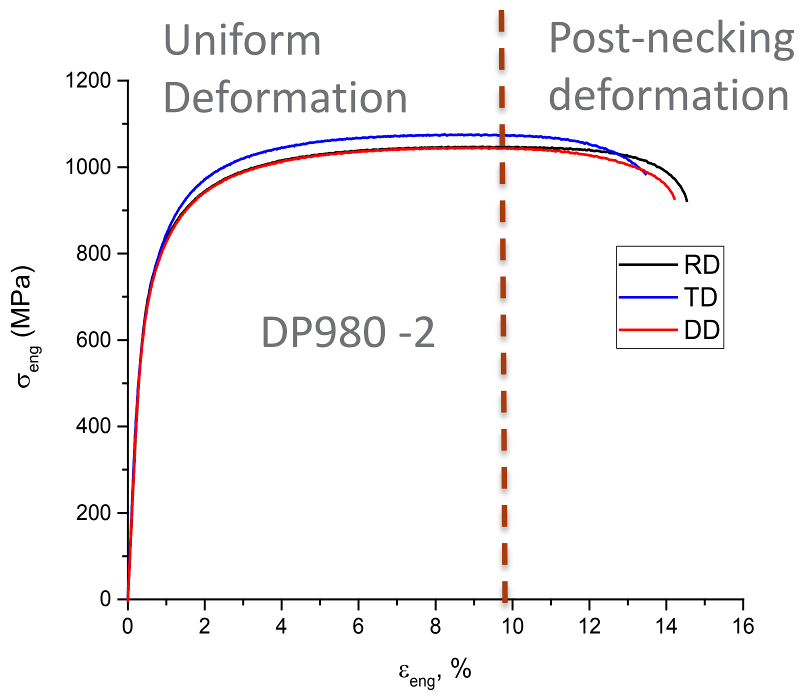




DP980-2

Task 2: Tensile properties





With similar strength level, DP980 -1 has much lower uniform elongation compared with DP980-2, but with higher post-necking deformation.

Task 2: Accumulated rolling & tension test

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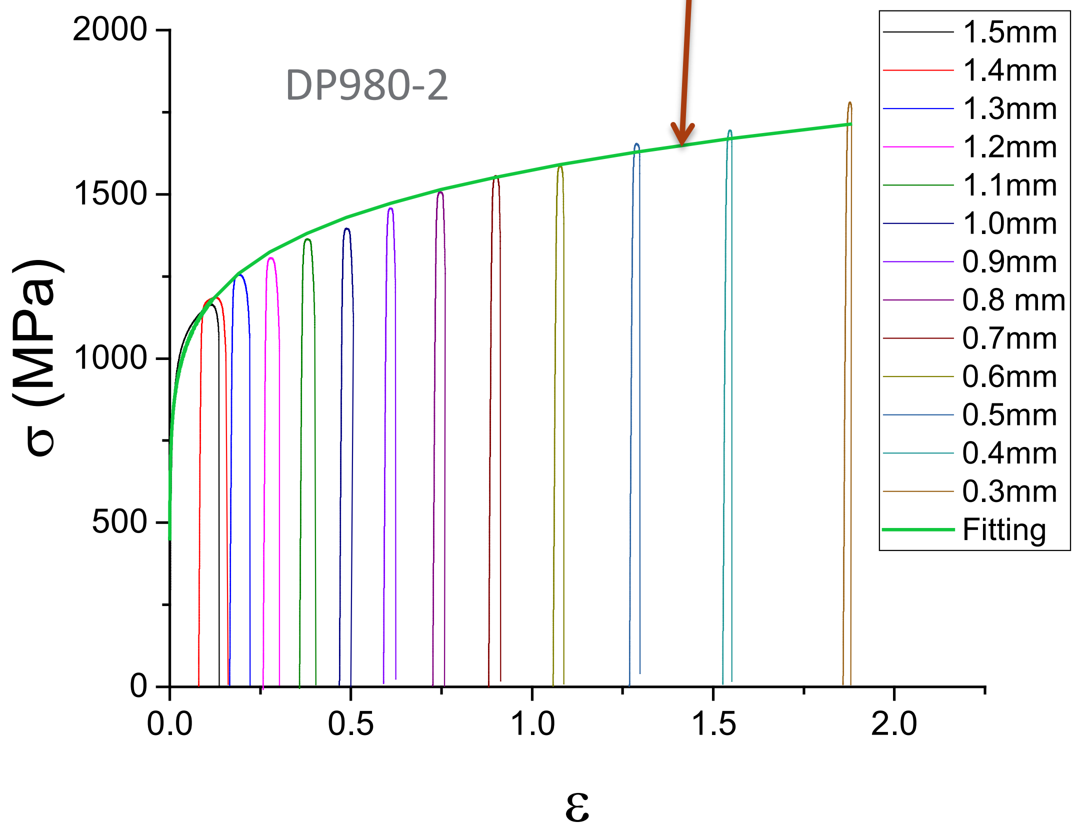
The accumulated rolling & tension tests are used to determine flow behavior of materials at large strains.

$$\sigma = 1574.4\varepsilon^{0.1348}$$



Accumulated Strain

Tensile Strain

$$\varepsilon = \frac{2}{\sqrt{3}}\ln\frac{t_0}{t} + \varepsilon_t$$

These results are needed in macro shearing simulation, including trimming & hole piercing.

Task 2: Characterized phase properties: - Martensite and Ferrite

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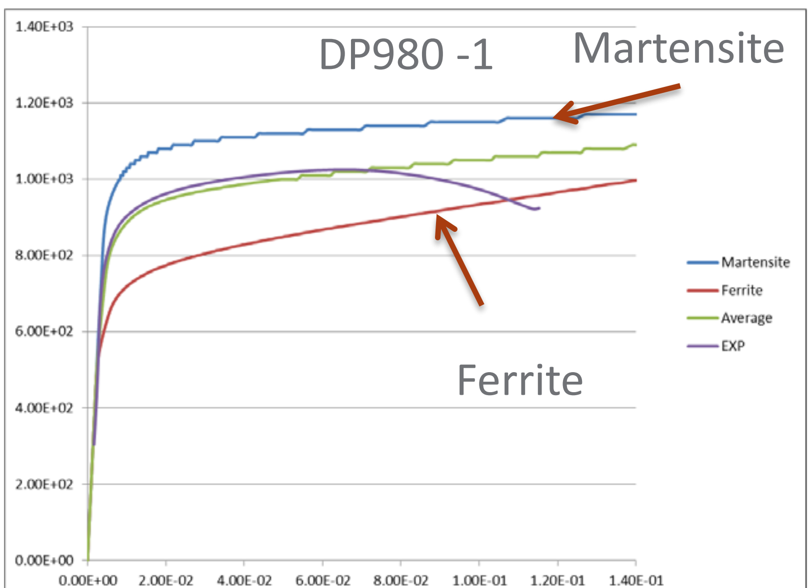
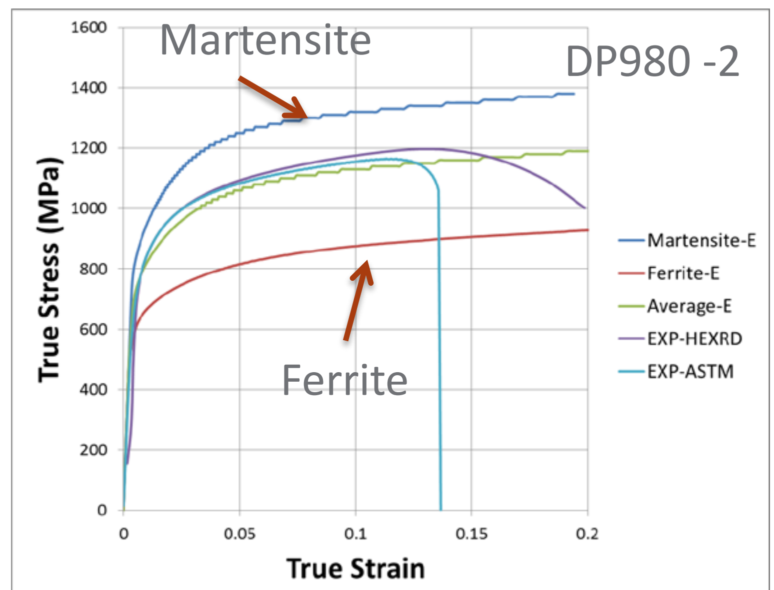
- The HEXRD determined initial texture and phase volume fractions in the two DP980 alloys are used as the input parameters into the EPSC / CPFE models.
- An iterative method is used to determine the individual phase slip system parameters until the calculated lattice strains from the model match those obtained from in-situ HEXRD tension tests at each strain increment.
- The average phase stress-strain relationships are calculated form the EPSC / CPFE models with the phase slip system determined previously.
- The obtained phase properties will be used in microstructure-based models in both the macro-micro or micro-macro approaches.





Progress Summary:
Task 3: Trimming Experiments and Model Development

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- Performed straight edge trimming and hole punching at different controlled clearances
- Cross sectioned sheared edges and performed quantitative edge characterizations
- Developed trimming/hole punching model and obtained fracture criterion for the trimming model based on sheared edge geometry obtained experimentally for the corresponding steel
- Examined effects of microstructural variability on predicted trimmed edge variability.

Task 3: Trimming Experiments by Ford and Oakland University

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Automated press cell

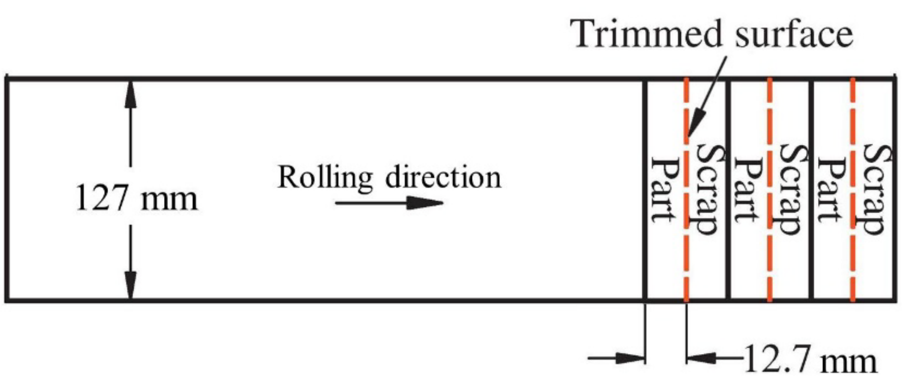
Decoiler

Straightener & feeder

65 ton mechanical press

Trimming die in the press

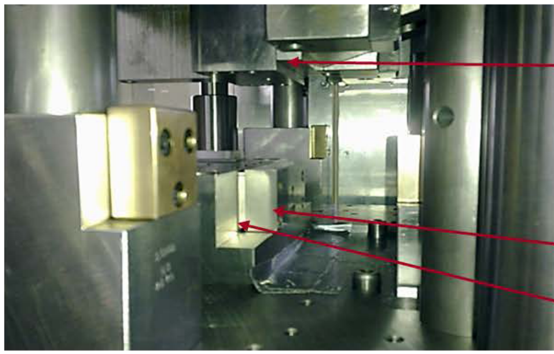
Cyclic trimming of UHSS from coil



Experimental die

Task 3: Trimming Experiments by Ford and Oakland University

- Studied sheared edge characteristics with respect to clearances and die wear



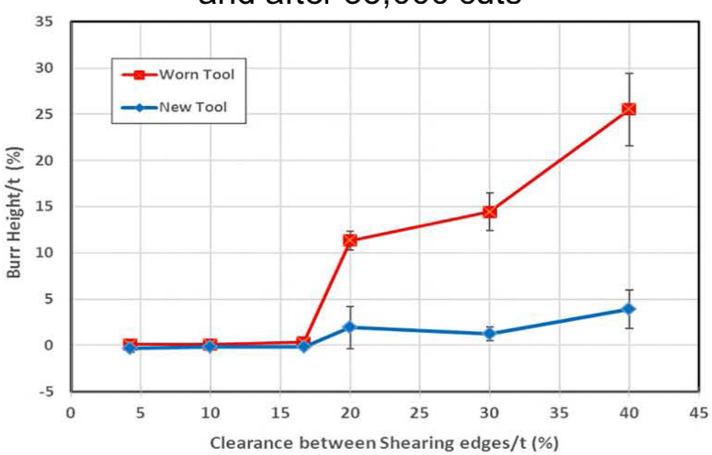
Upper trimming Tool

Lower trimming tool

Stainless steel shim

Trimming Edges

Burr height measurement for the new tool and after 35,000 cuts



Burr height Measurement: Mitutoyo MDC-1" SFB Micrometer

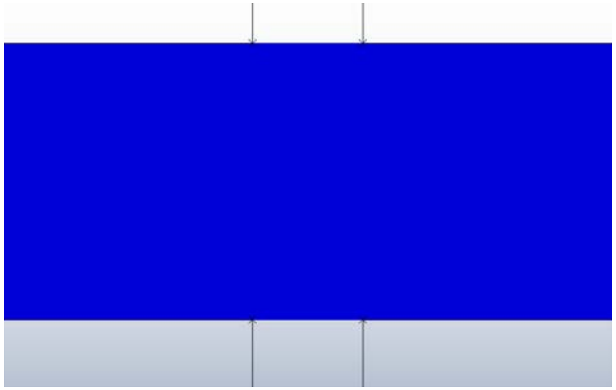
Each data point on burr height is based upon 10 measurements along the sheared edge repeated for 10 samples

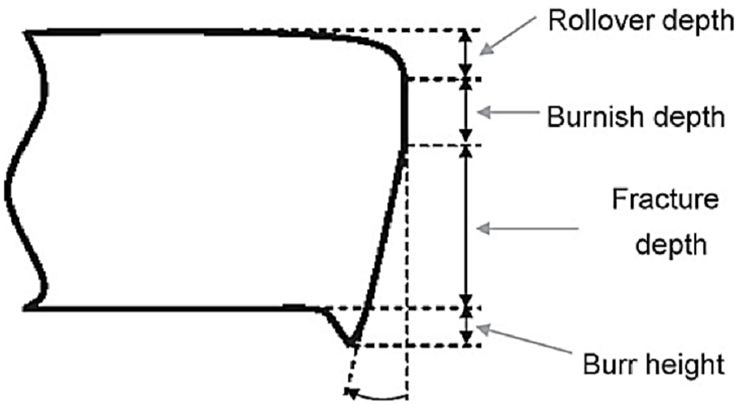
Task 3: Trimming Model Development and Model Parameter Calibration

- Commercial finite element code
- Large deformation with adaptive meshing
- Input flow stress from accumulative rolling and tensile test
- Damage modeled with Johnson-Cook damage model

Sheared edge profile (c=40%t)

$$D = \int_0^{\varepsilon_p} \frac{d\varepsilon_p}{\bar{\varepsilon}_f} \qquad \bar{\varepsilon}_f = A_0 + Ae^{-B\eta}$$

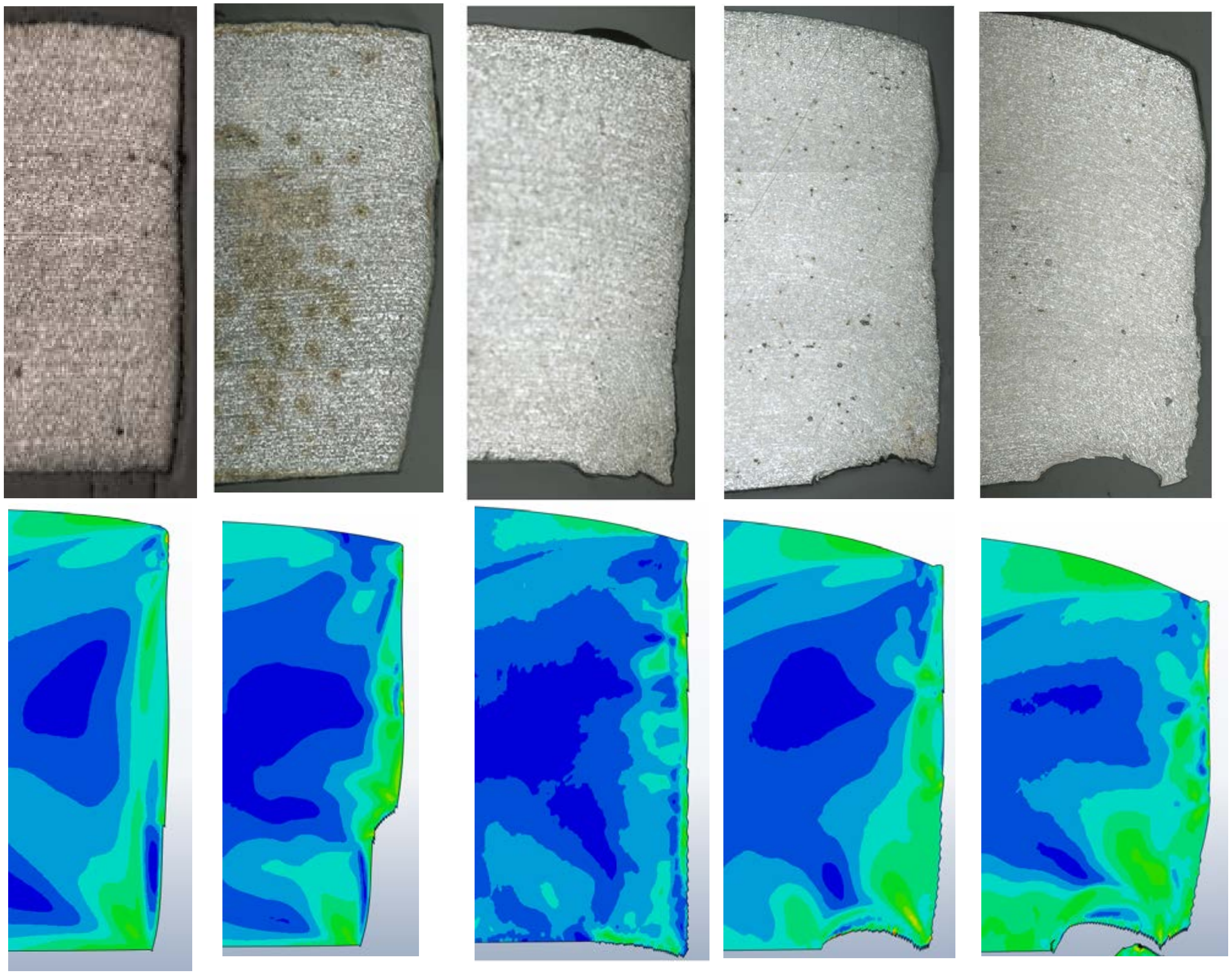




Task 3: Identification of Damage Parameters

Shearing edges at different clearances: experiments and simulations: DP980-1

4% 10% 20% 30% 40%



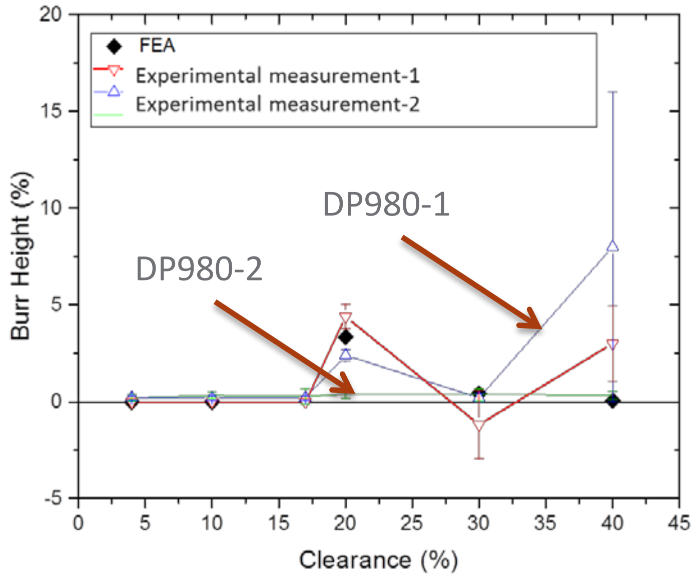
$$\bar{\varepsilon}_f = A_0 + Ae^{-B\eta}$$

$$A_0 = 1.3$$

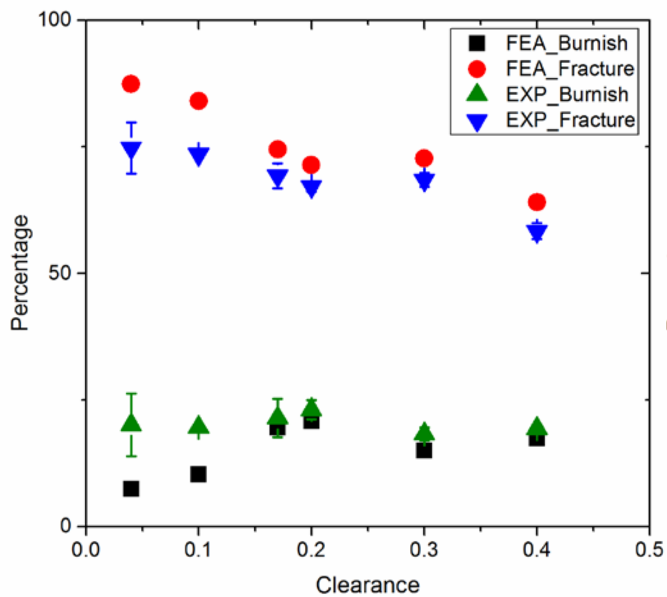
$$A = 0.5$$

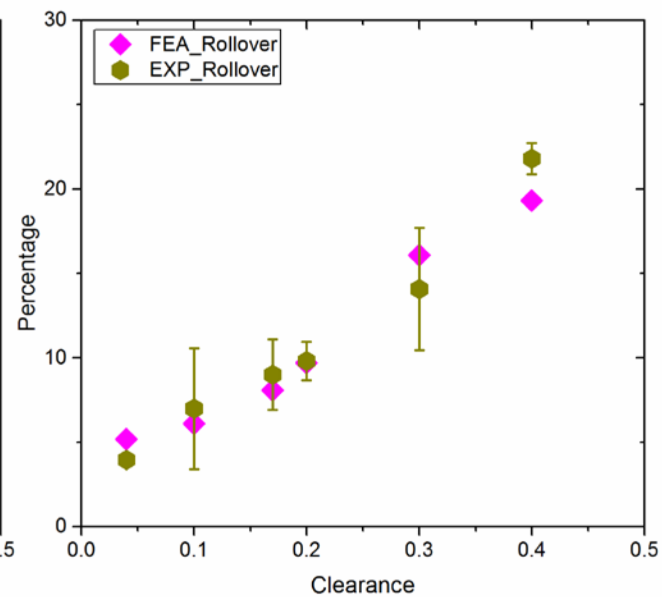
$$B = 0.5$$

Task 3: Trimming Simulations vs Experimental Results



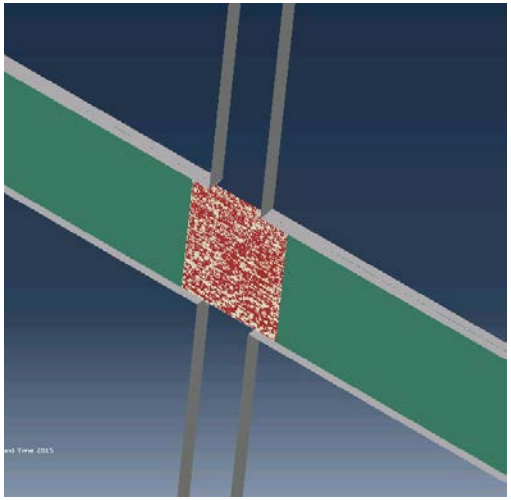
- The burr height, burnish, fracture and rollover percentages and measured data are quantitatively comparable
- Predicted burr geometry >90% accurate for different DP980 under different clearances
- Very large ***burr height variation*** for clearance of DP980-1 at 40% clearance





DP980-1

Task 3: Trimming Simulations- Effects of edge microstructure variability



- The flow stress of element was determined using the rule of mixtures.

$$\sigma(\varepsilon) = \sigma_F(\varepsilon) f_F + \sigma_M(\varepsilon) f_M$$

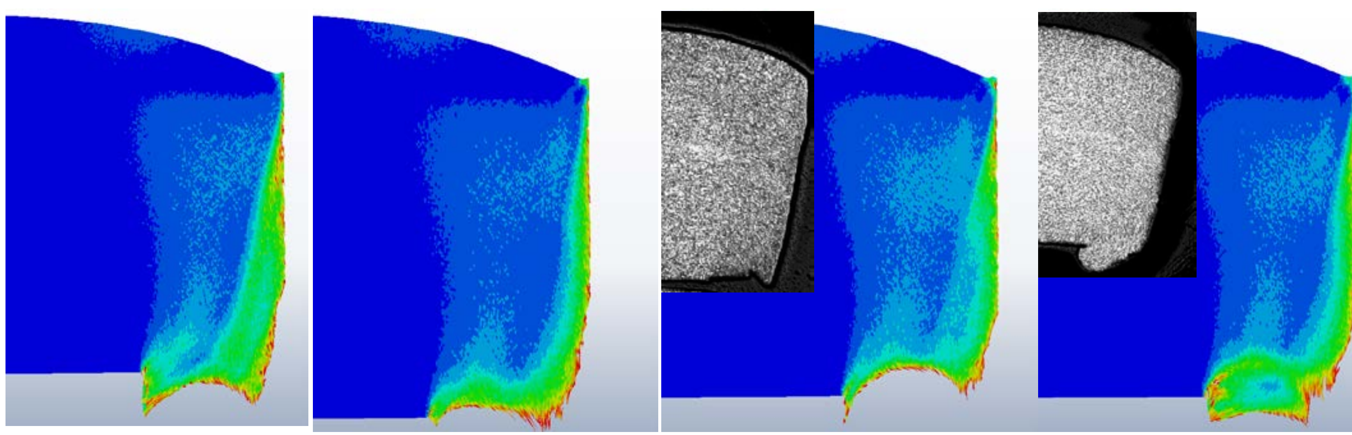
- For a given MVF value, heterogeneous damage parameters were also assigned to each element through Johnson-Cook damage parameter a_0

$$\varepsilon^f = a_0 + a_1 e^{-b\eta}$$

$$a_o^{input} = 1.3 * \left(1 - \ln\left(\frac{MVF}{0.57}\right)\right) + 0.2 * 1.3 * C * (-1)^{(C*1000)}$$

Influence of MVF
57% is the average MVF

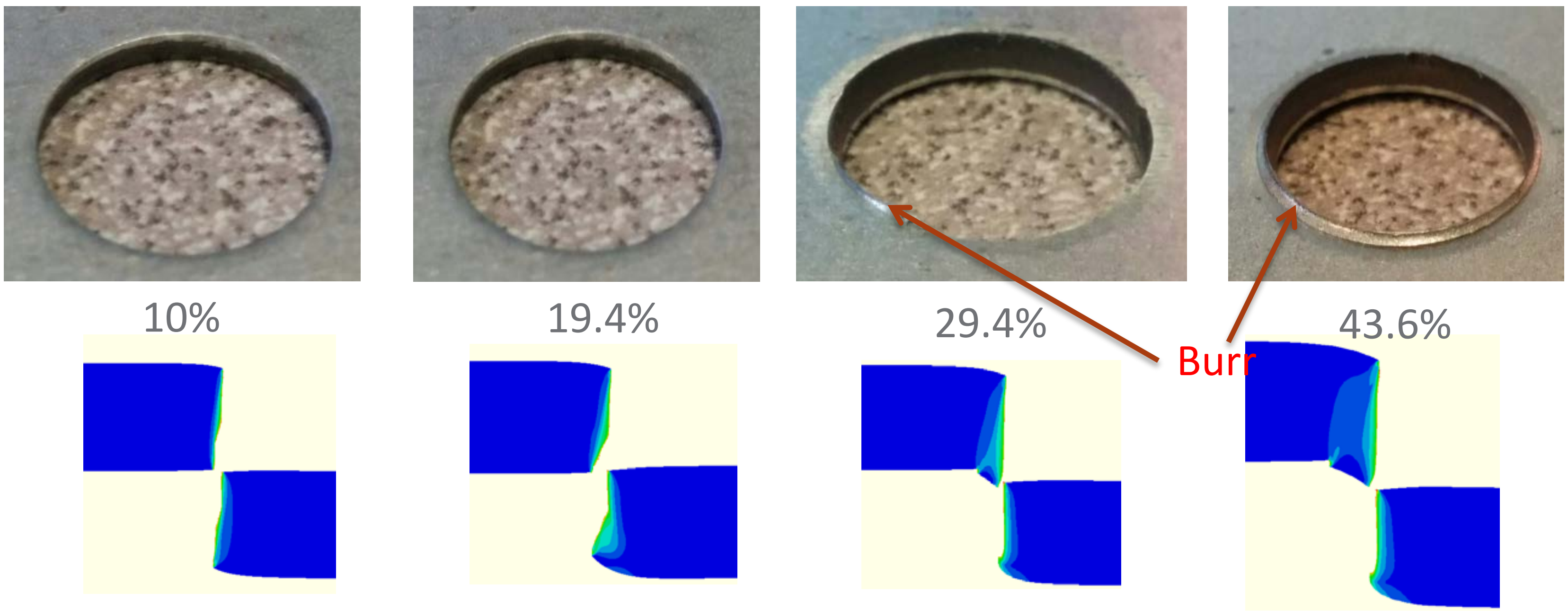
The max influence of morphology is 20%
C is a random number 0-1



Predicted edge variation for DP980-1 with 40% trimming clearance

Task 3: Hole Piercing Experiments and Preliminary Simulation Results

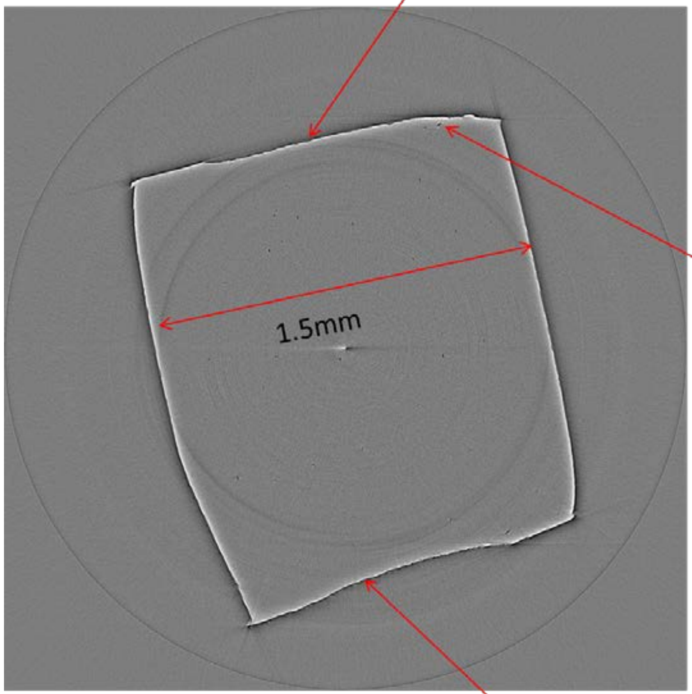
- Hole piercing has been performed on DP980-2 steel with different clearances: No burr for clearances <19.4%; partial burr exists around the circumference for clearance of 29.4%; circumferential burr observed for clearance of 43.6%.



- Preliminary simulations using the fracture parameters determined for the trimming model shows similar results: No burr predicted for clearances <19.4%; and large burr for 43.6% clearance. Small burr for 29.4% clearance, but the burr variation cannot be captured by the 2D model.

Task 4. Microscopic Damage Characterization of Shear Affected Zone

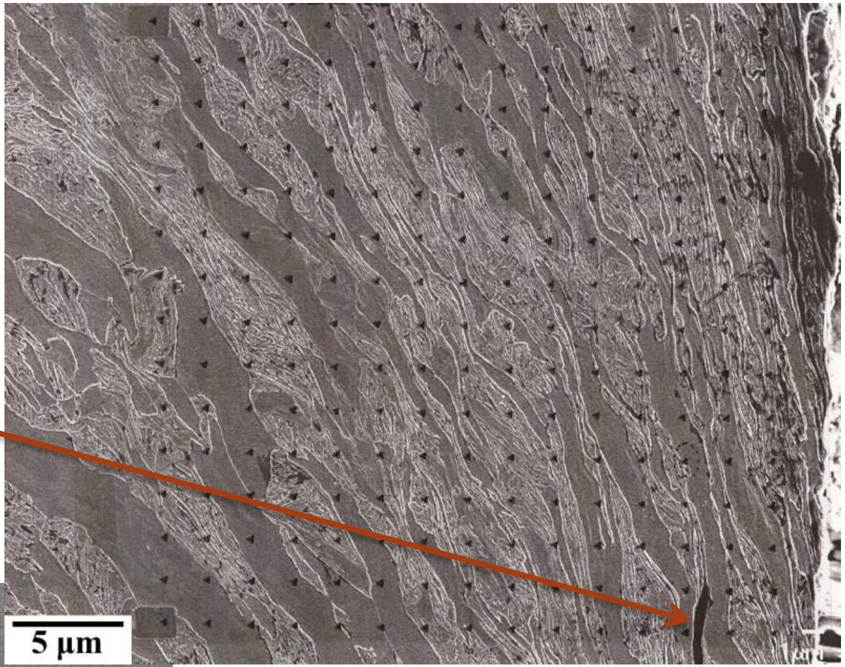
sheared edge

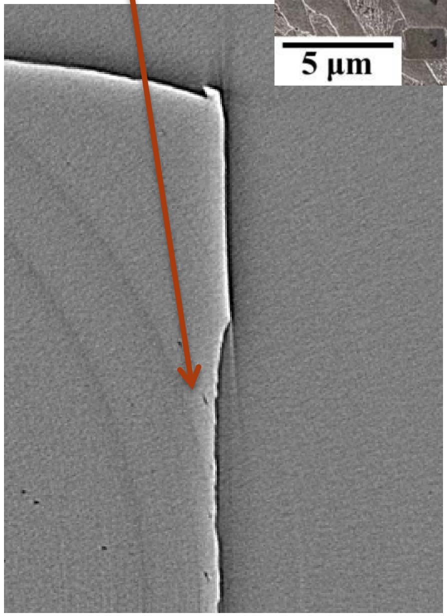


sheared edge

3D tomography performed at APS Beamline 2

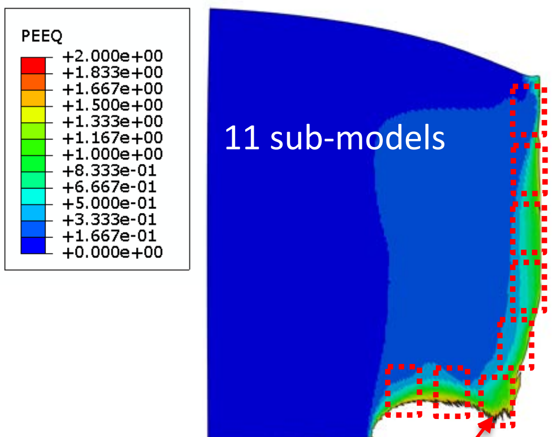
Possible internal Damage due to shearing

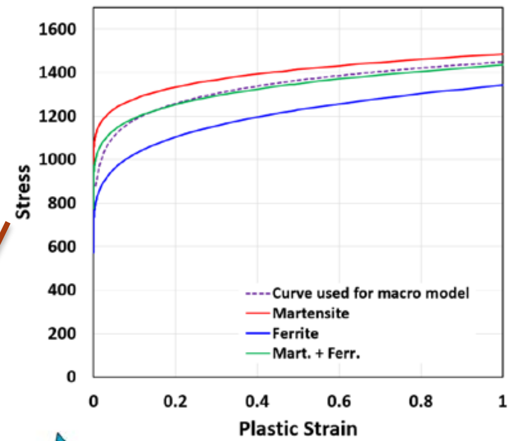


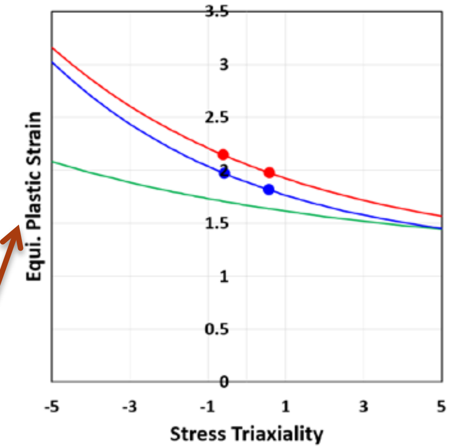


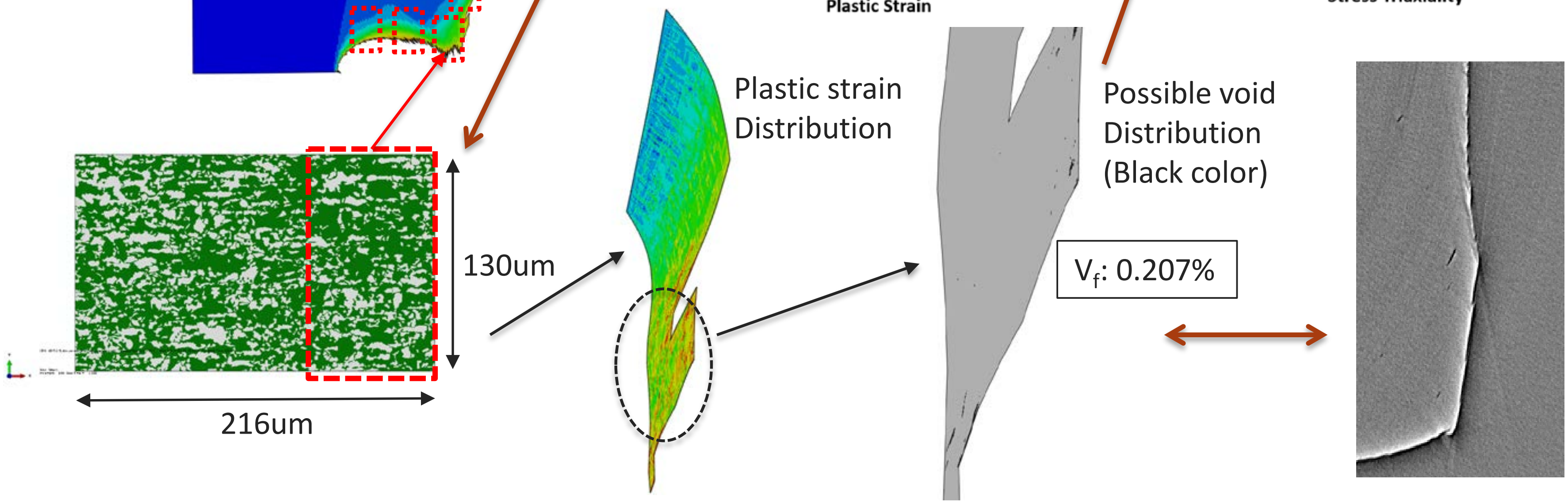
Progress Summary:
Task 4: Microstructural Damage Prediction at SAZ

- Micro-scale sub-model used to simulate trimming induced internal micro-cracking/void









- Est. void fraction along the sheared edge will be used as the input information in the subsequent stretchability simulation.

Progress Summary:
Task 5. Macroscopic Fracture and Stretchability Prediction with Experimental Validation

- Some preliminary hole expansion tests have been performed for DP980-2 steel for hole-pierced with different clearances

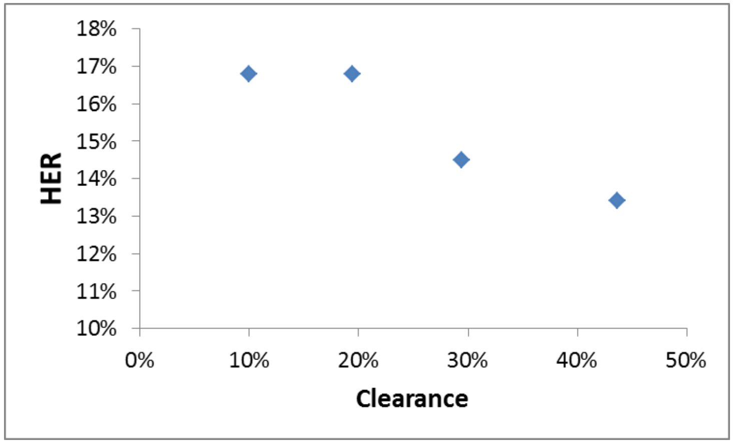
10%

19.4%

29.4%

43.6%

- Measured HER is found to decrease with increasing hole punching clearances



Responses to Previous Year Reviewers' Comments

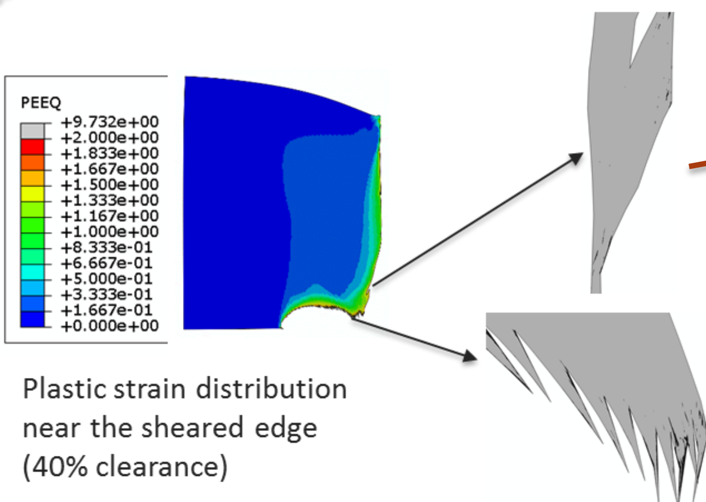
- This is the first year the project is being reviewed at AMR.
- No previous year's Reviewers' Comments available yet.

Collaborations

- Experimental materials characterizations at micro- and macro-scales (AK, USS, OU, PNNL)
- Experimentally trimming task with die wear (Ford+OU)
- Phase property and SAZ characterizations (PNNL+APS)
- Experimentally obtain quantitative relationship between edge stretchability and edge quality indicators:
  - Straight edge (Ford+OU)
  - Hole punch (AK+USS)
- Develop predictive modeling capability linking microstructures to trimming conditions to edge stretchability (PNNL)
- Develop optimized microstructure and process parameters based on ability of sheared surface to stretch (PNNL+ AK + USS + Ford).

Remaining Challenges and Barriers -- Future Work

- Task 5. Macroscopic fracture and stretchability prediction with experimental validation
  - Incorporate trimming induced damage as state variables at the edges of the stretchability sample
  - Consider in-plane and through thickness microstructural heterogeneity
  - Predict tensile fracture
  - Validate model
- Task 6. Develop optimized process parameters and microstructures for sheared edge stretchability



Plastic strain distribution near the sheared edge (40% clearance)

Evaluation of Crack/void along the sheared edge from sub-model simulation

Example of Stretchability Simulation