Edge Fracture in Mixed Microstructure Steels

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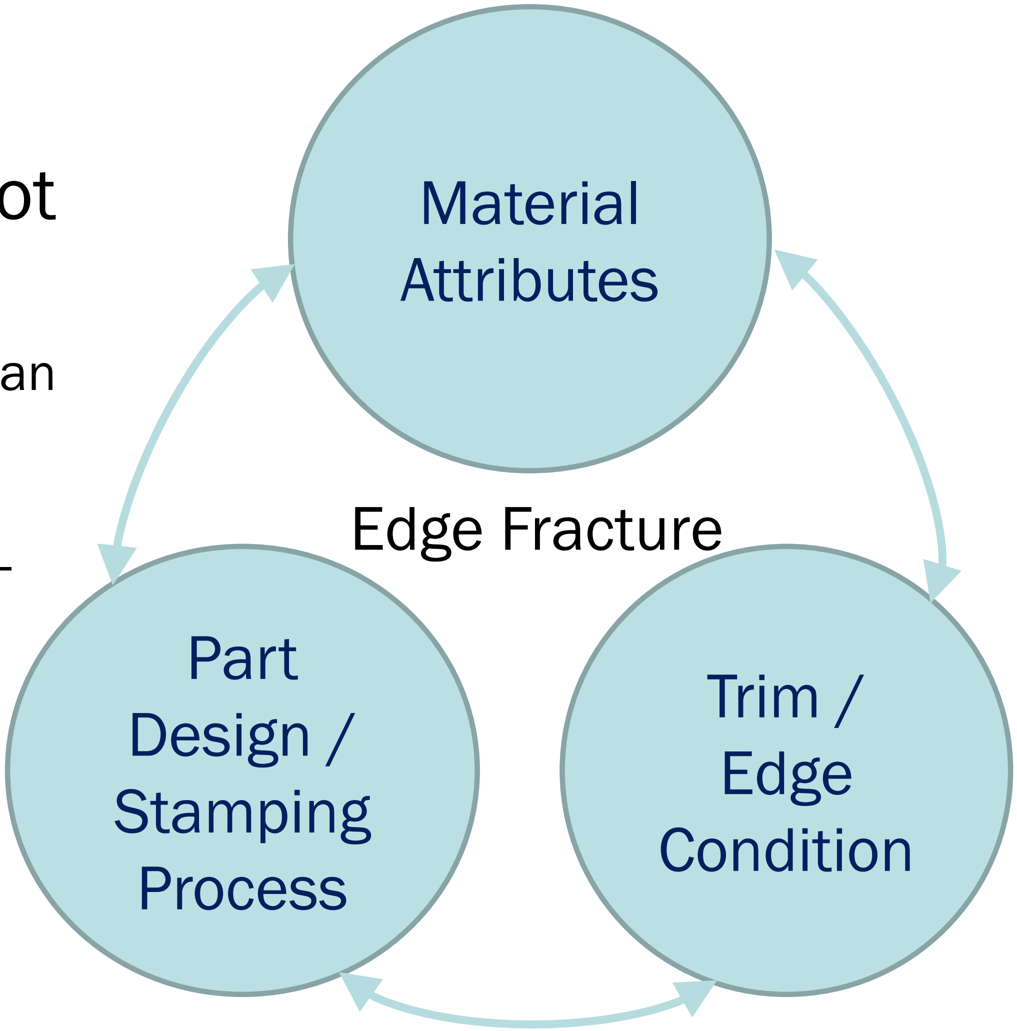
Presentation Outline

- Edge Fracture – Background
- Past Case Studies
- Material Evaluations on Production & Trial Material
  - Edge quality effects
  - Hole expansion testing on current and new grades of AHSS
  - Nano-indentation and microstructure
- Concluding Remarks

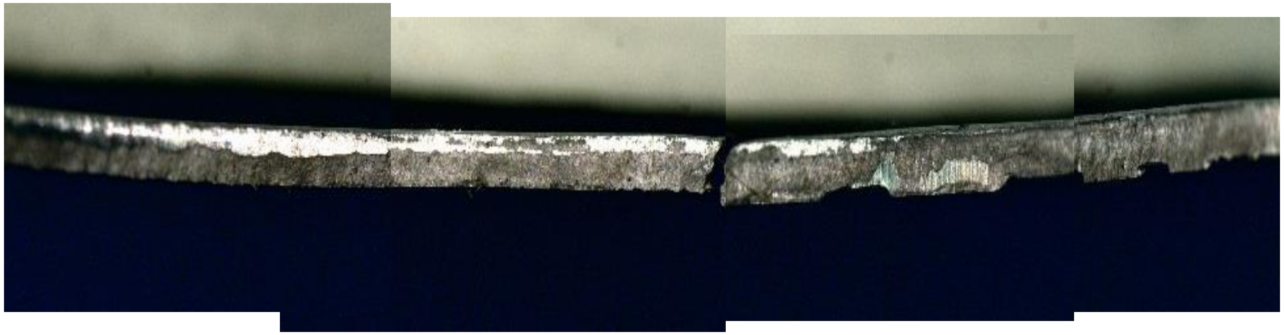
Edge Fracture – Background

- Fracture initiating at a trimmed edge, typically not predicted by an FLC
  - A local formability phenomena: an inter-relationship between steel microstructure, damage during trimming, and subsequent edge-stretch during forming.
  - AHSS more susceptible than single phase materials (Low Carbon, HSLAs)



Edge Fracture – Background

- Edge fractures typically occur in the highest edge strain area in the presence of a rough trimmed edge.
  - Typically during drawing or from a stretch flange after a rough die trim

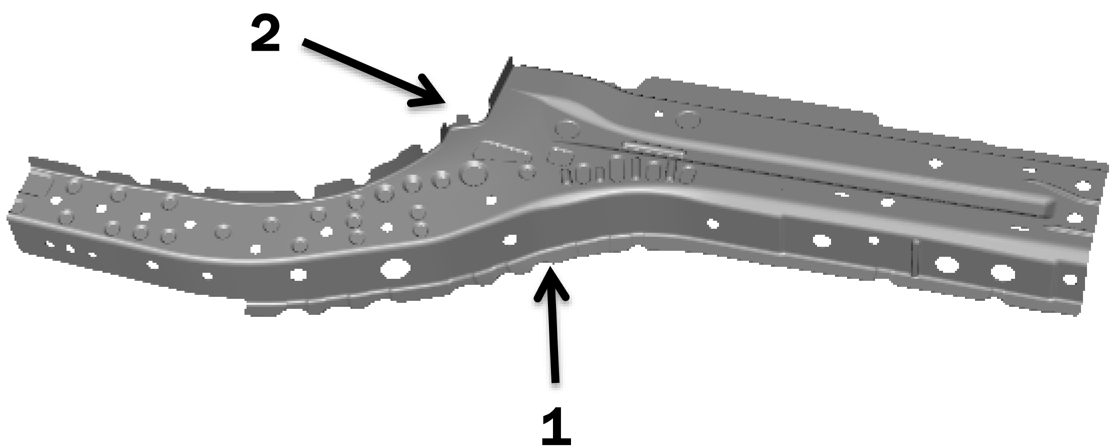


Edge Fracture Case Studies

- Edge fracture instances are not isolated to particular steel suppliers, grades of AHSS, gauge, or coating.
- Case study subset selected to show common root causes and resolutions.

Part	Grade
Front Compartment Rail	DP780/420
Torque Box	DP980/550
Rear Rail Inner	DP590/340
Center Pillar Inner	MP980/700
Lock Pillar Inner	DP780/420
Hinge Pillar Outer	DP590/340
Front Body Hinge Pillar	DP590/340
Sill – U/B #2 CR	DP590/340
Rocker Inner	DP780/420
Front Rocker Inner	DP980/700

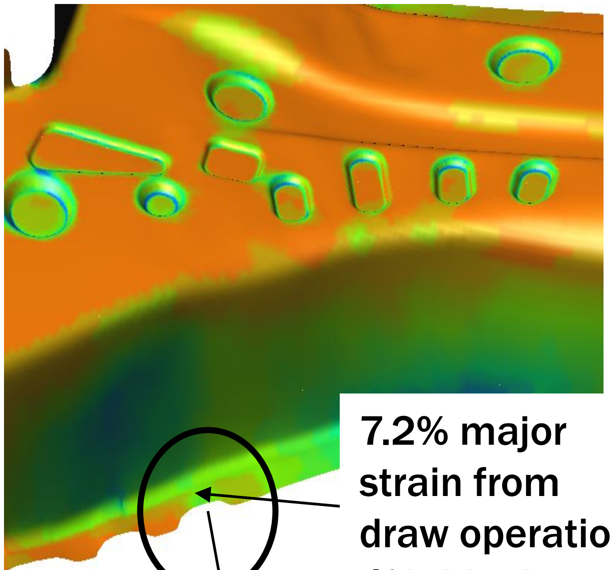
Front Compartment Rail – CR780T / 420Y (DP)



Multiple Fracture Locations

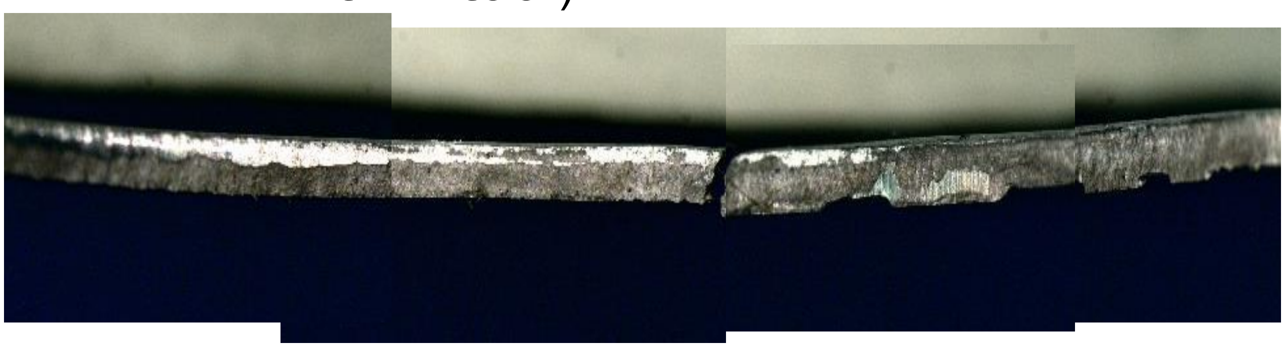
1. At notch
2. Tab

Front Compartment Rail – CR780T / 420Y (DP)



7.2% major
strain from
draw operation
4% thinning

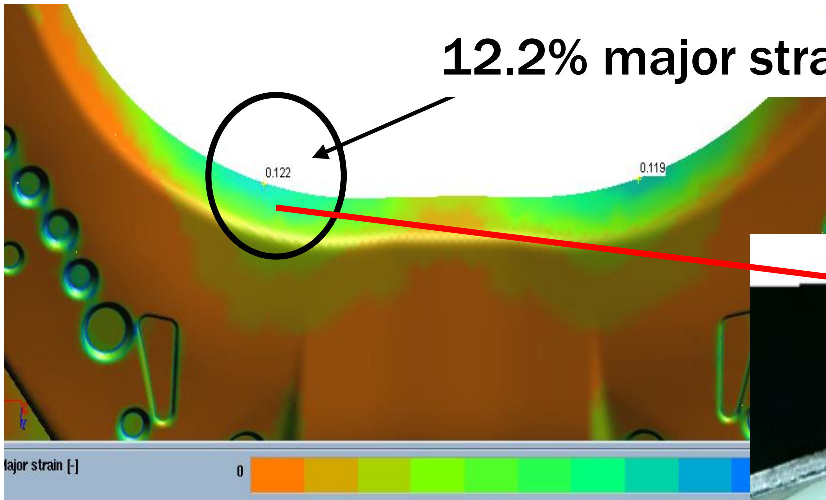
- Fractures at locations 1 (notch) accounted for 2/3 of initial fractures
- Predominance of fractures on RH only, occurring in the trim die
- Materials within specification, trim clearances OK
- Part nesting (unsupported on trim tool)



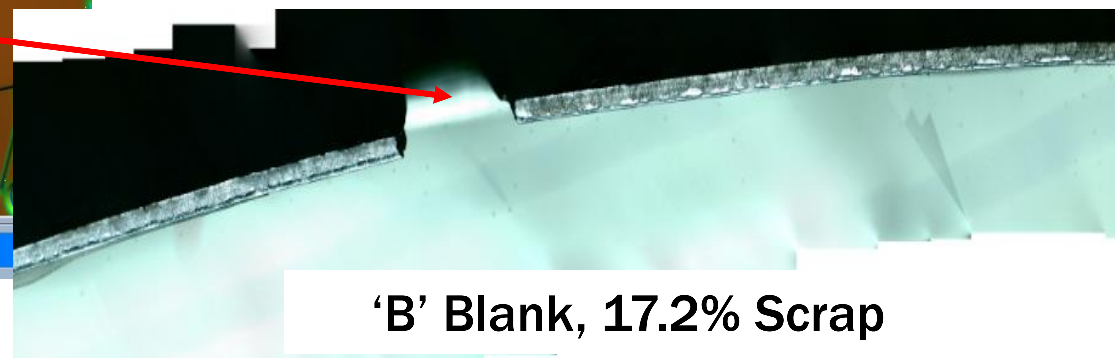
Front Compartment Rail – CR780T / 420Y (DP)

- Fracture Location #2 (occurring in the draw die)

12.2% major strain

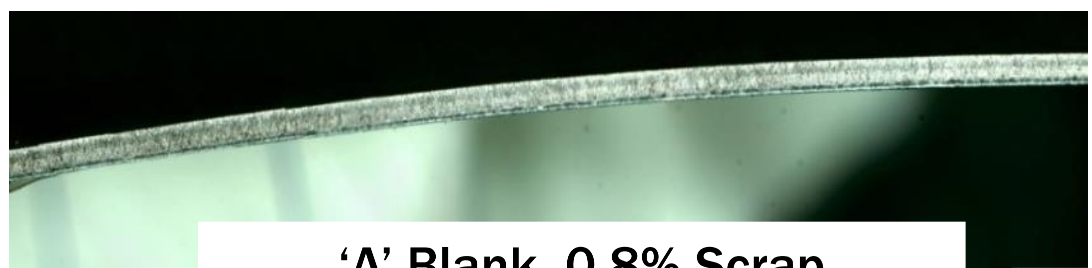


- Several 'B' blanks showed splits resulting in scrapped parts



'B' Blank, 17.2% Scrap

- 'A' blanks showed very few or no splits



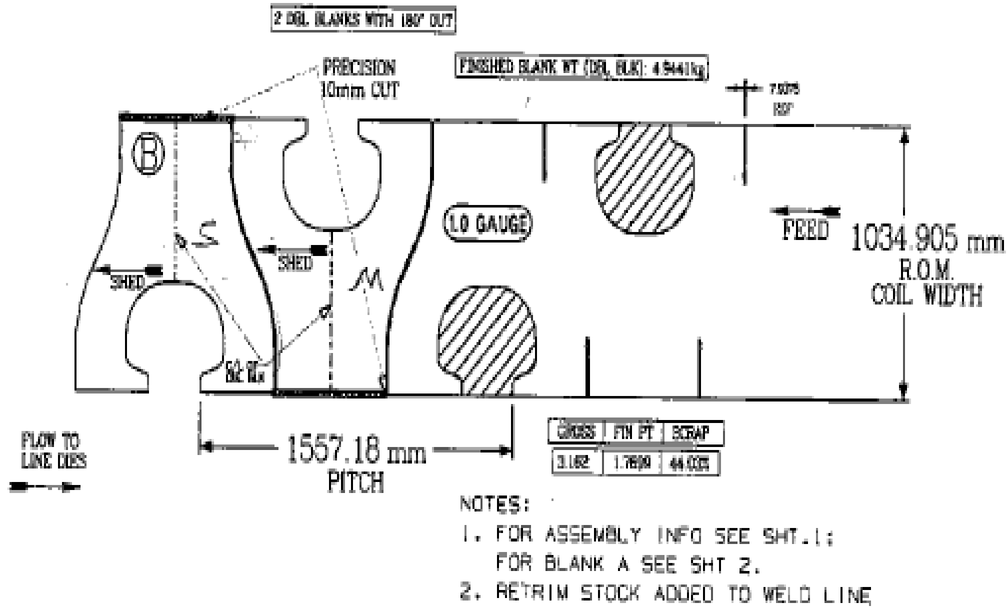
'A' Blank, 0.8% Scrap

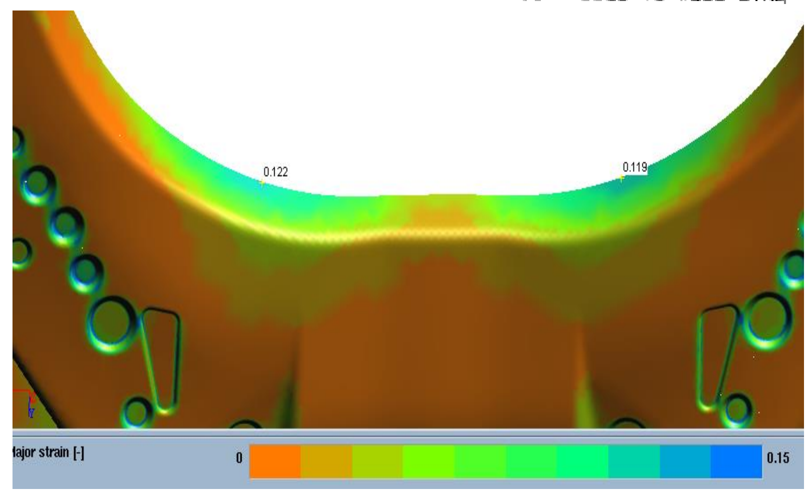
Front Compartment Rail – CR780T / 420Y (DP)

- This design is frequently used for double attached left / right compartment rails (material utilization)

- Significant edge stretch condition during the draw in the 'horse collar' area

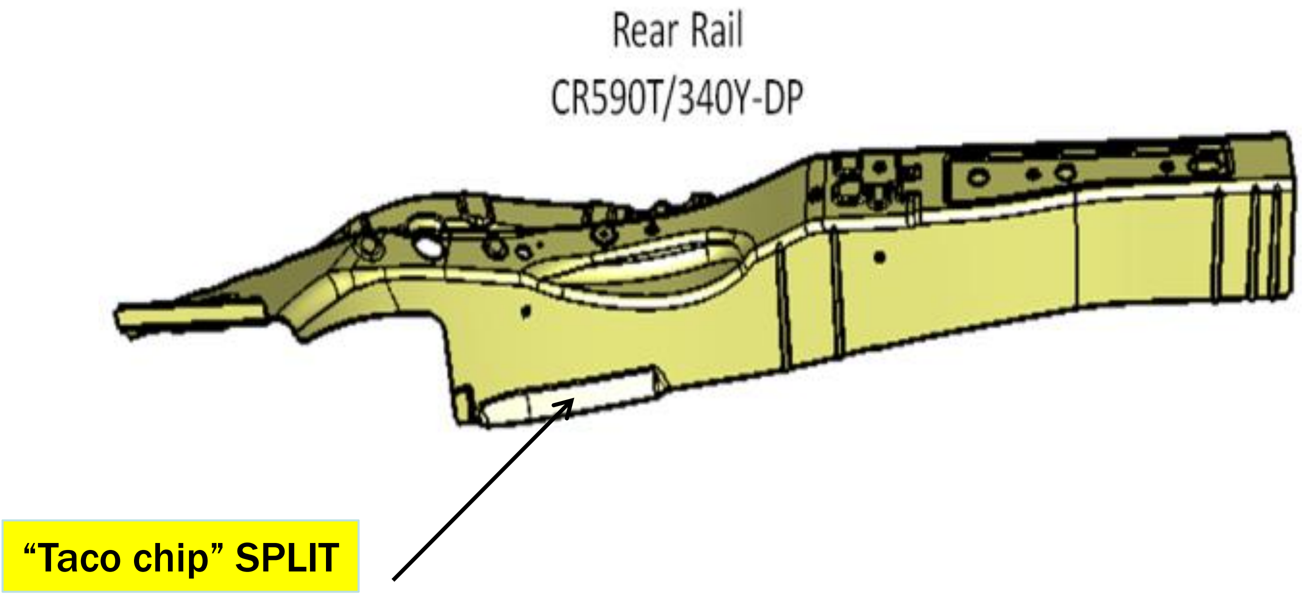
- Also, thin bypass condition between common trim lines (difficult to support) affected trim quality.





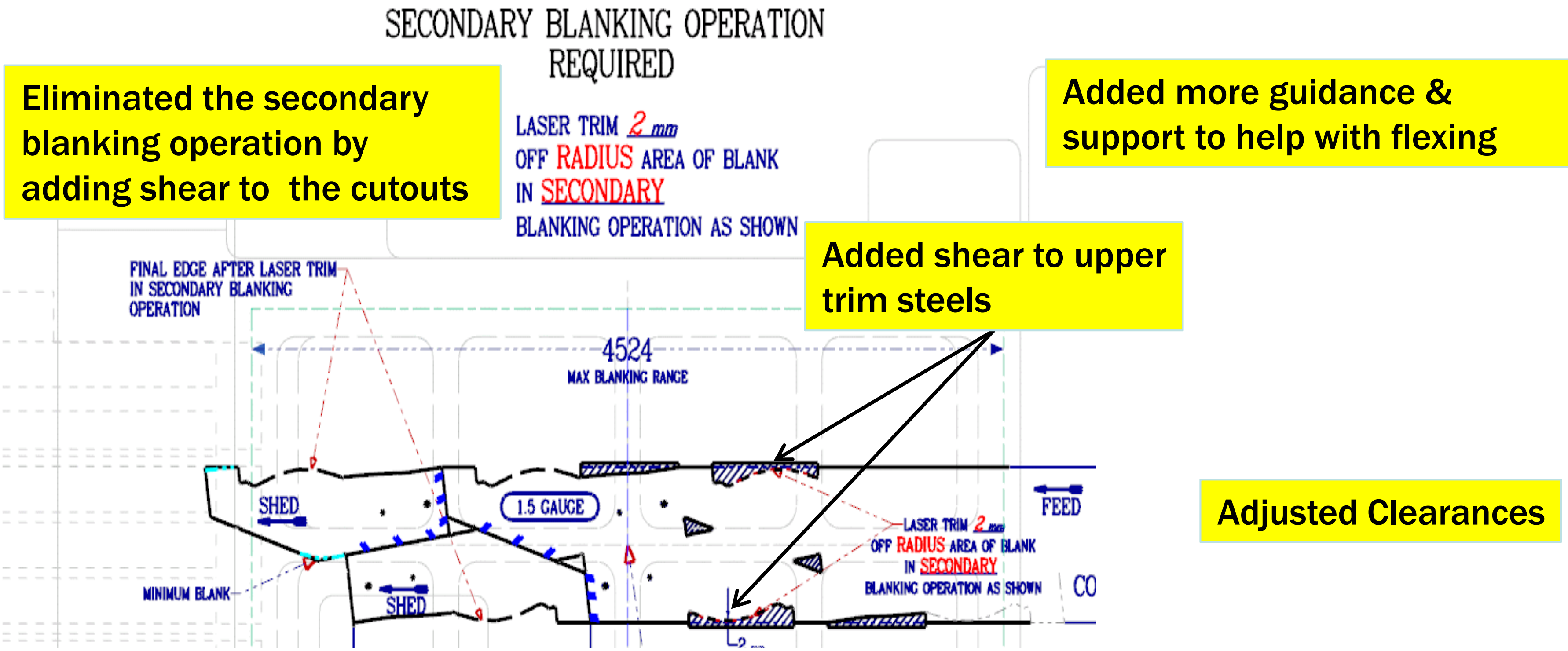
Rear Rail CR590T / 340YDP

- Intermittent edge fracture predominantly on one hand of part.
  - Size and exact location of fractures were variable run-to-run.



Rear Rail CR590T / 340YDP

- LH vs. RH trim conditions made more robust.
- Trim steel insert maintenance required (sharpening).

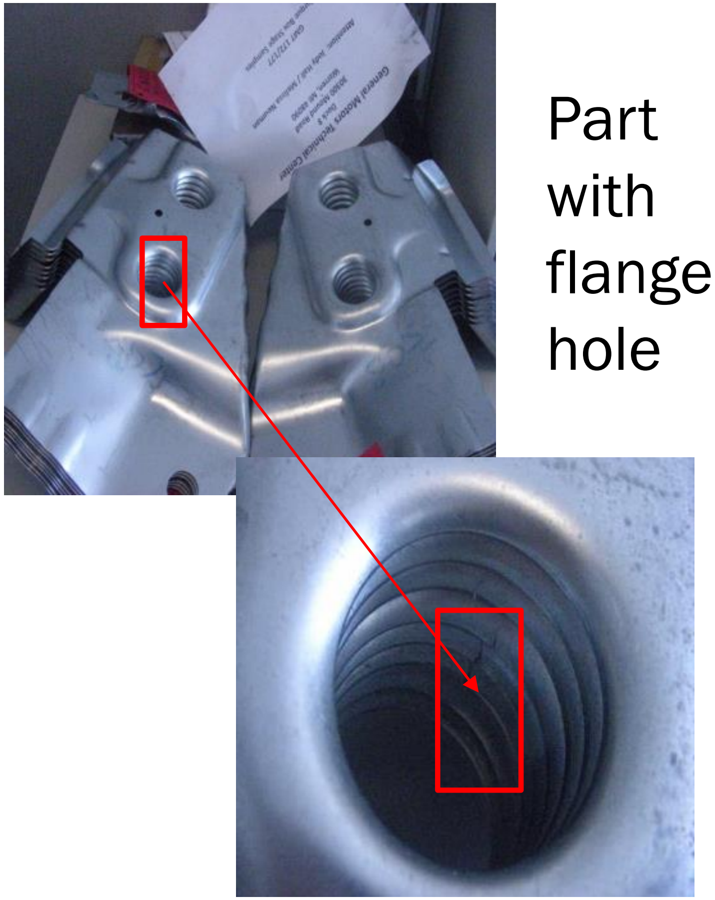


Potential Sources of Poor Trim Quality

- Poor Nesting (Trimming in Air)
- Die Breathing and Flexing
- Die Guidance
- Improper Clearance
  - Typically too tight
  - 13-15% recommended for most AHSS
- Sharpness of Trim Steels

Part with Flanged Hole – DP980T / 550Y

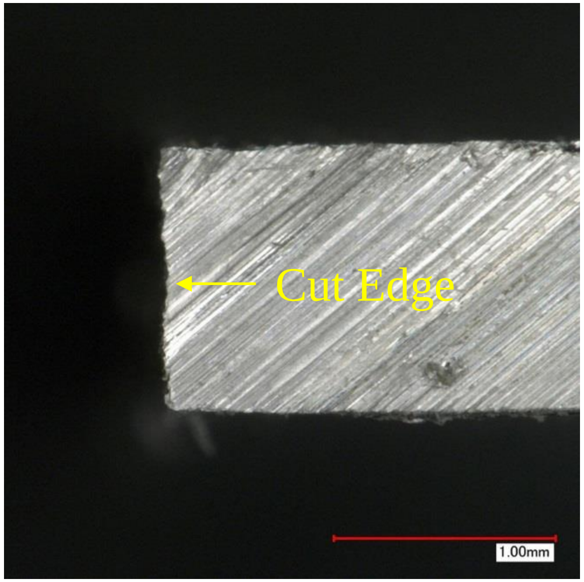
- Part hole expansion is 13%
- Material capability is 12-15%
  - Other material properties within specification
  - Hole Expansion (recently added to qualification approval process in May 2014)
- Design not robust for material capability
- Changed material to high yield ratio CR980T / 700Y-MP-LCE
  - (HER ~ 30%)
- No issues-to-date



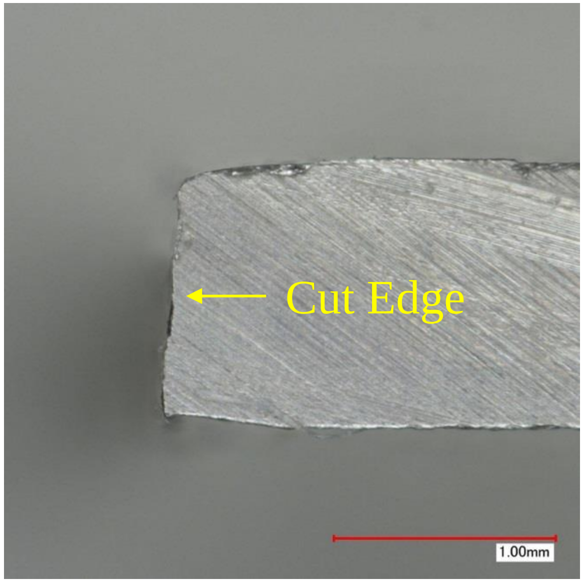
Part with flanged hole

Effect of Laser Cut vs. Die Cut Edge Quality

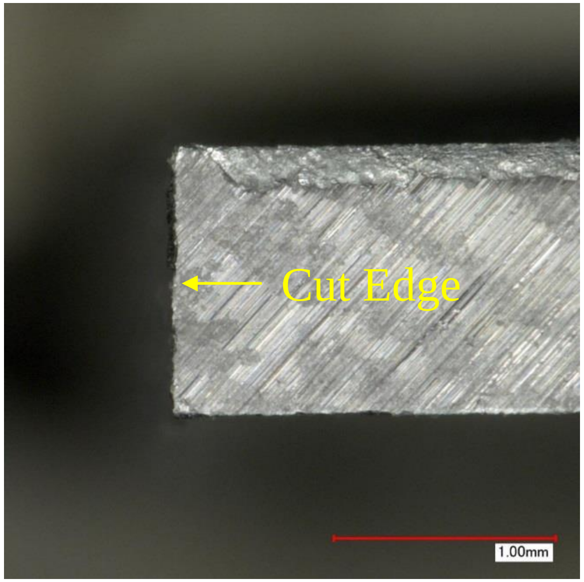
Laser Cut

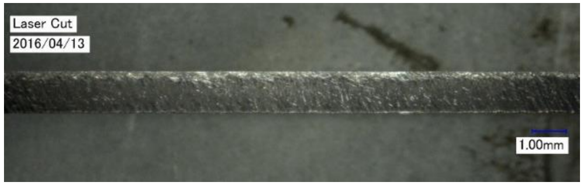


Die Cut



Water Jet Cut





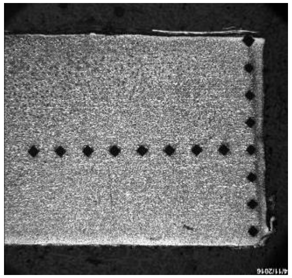
Laser Cut – Edge Profile

Die Cut – Edge Profile

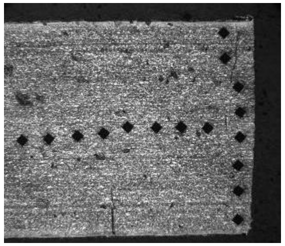
Water Jet – Edge Profile

Micro-Hardness Edge Profile Comparison

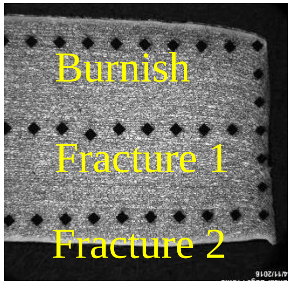
Laser Cut Profile

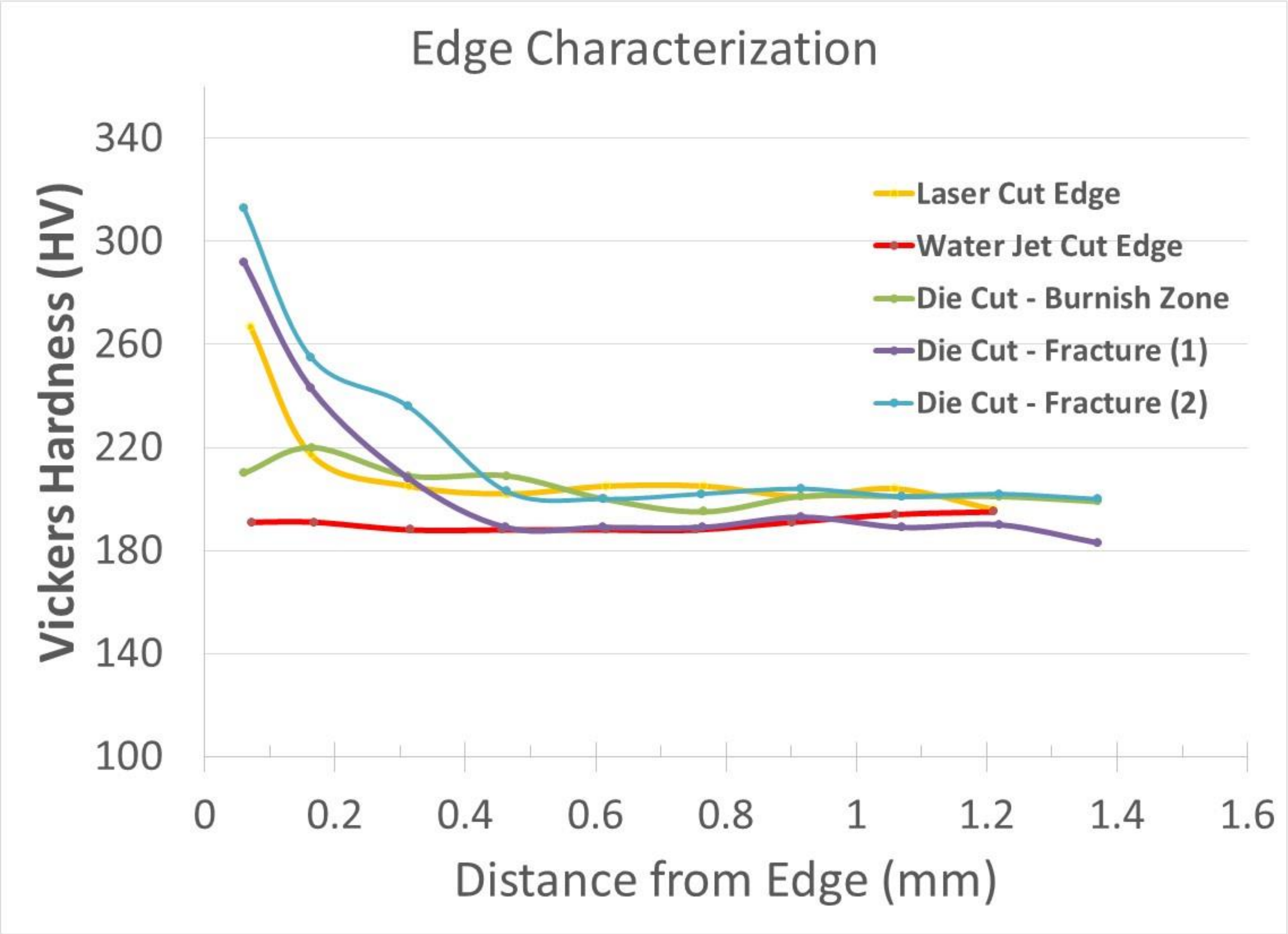


Water Jet Cut Profile

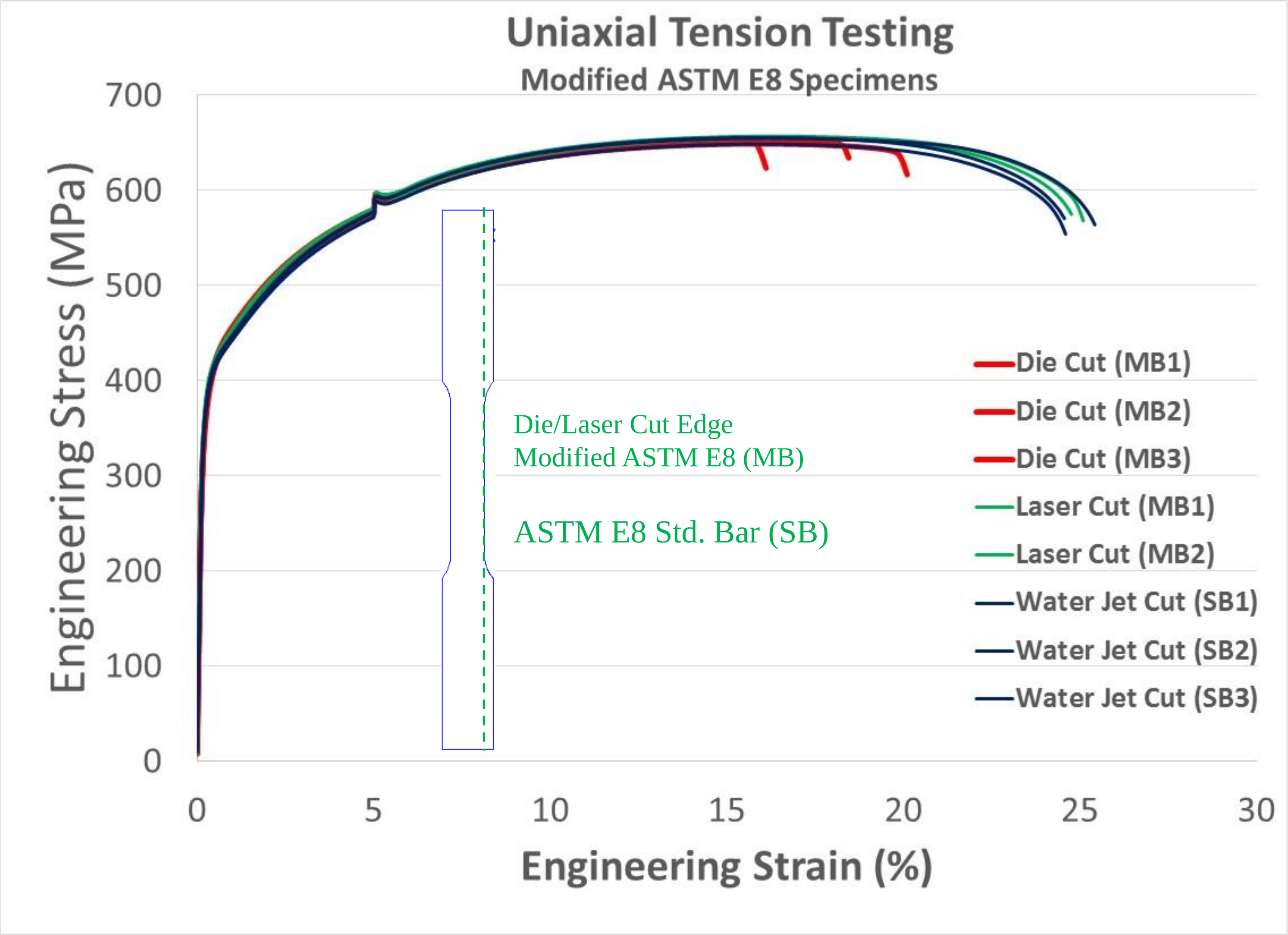


Die Cut Profile





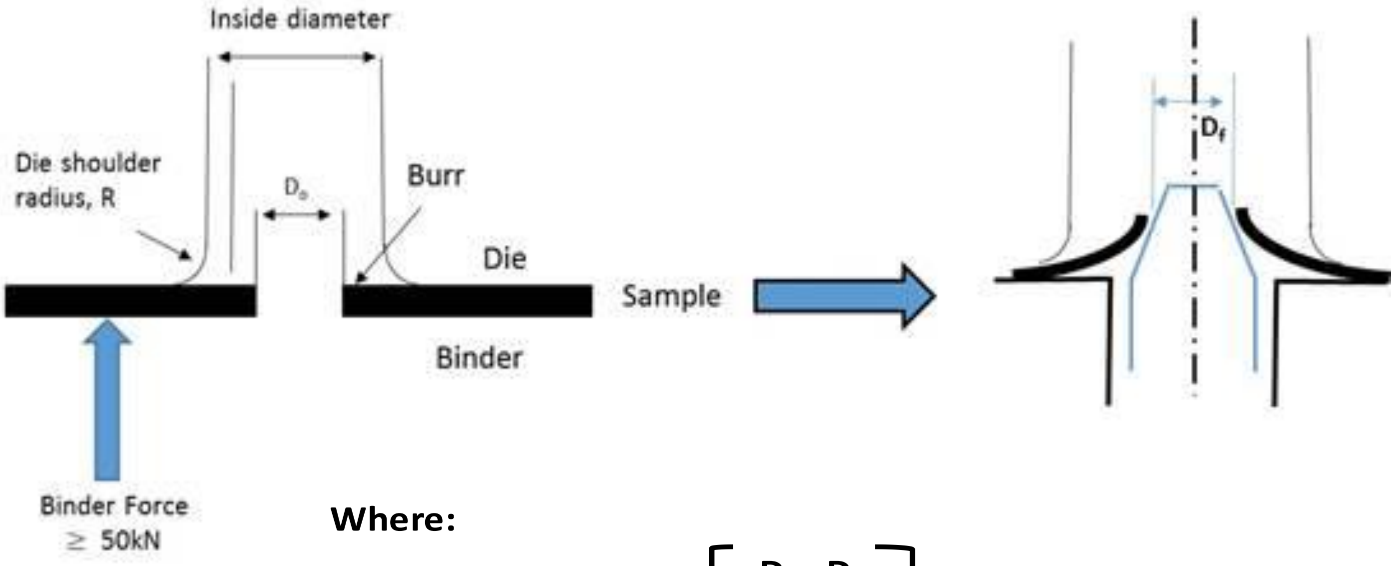
DP590 Cut Edge Performance Evaluation



Try-out vs. Production Blanks

- Laser cut blanks in try-out material are not a good indicator of potential edge fractures in production with die struck blanks.
- Stamping plants are concerned about receiving dies for secondary try-out when the dies have not stamped die struck blanks in primary try-out.
- Timing of production-intended blanks needs to ensure that delivery occurs before dies are shipped to home line.

Hole Expansion Testing



Where:

$$HER = \left[\frac{D_f - D_0}{D_0} \right] \times 100$$

- Variability of hole expansion testing exists due to variation in microstructure within a material, the quality of the sheared hole, and specific testing equipment site-to-site.
  - A tool for qualification of material and general understanding of edge stretch performance with an adequate sample size; however, challenges exist for use for lot acceptance testing.

Hole Expansion Testing

- 10 mm hole punching
  - Die clearance 0.2 mm

- Testing per ISO 16630
  - Speed: 0.5 mm/s
  - Testing in hole punch direction
  - Digital data acquisition until thru-thickness crack observed
  - 5 samples per material

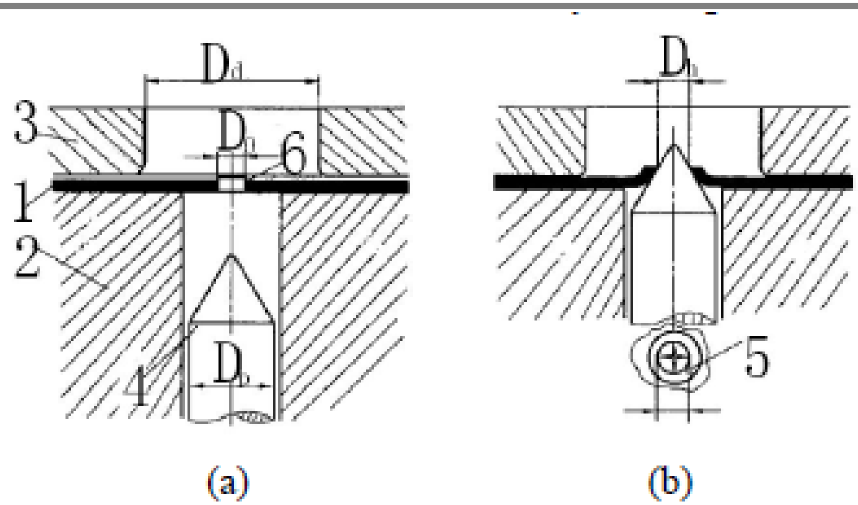


Fig. 1. Schematic diagram (a) before and (b) after the hole expansion test.

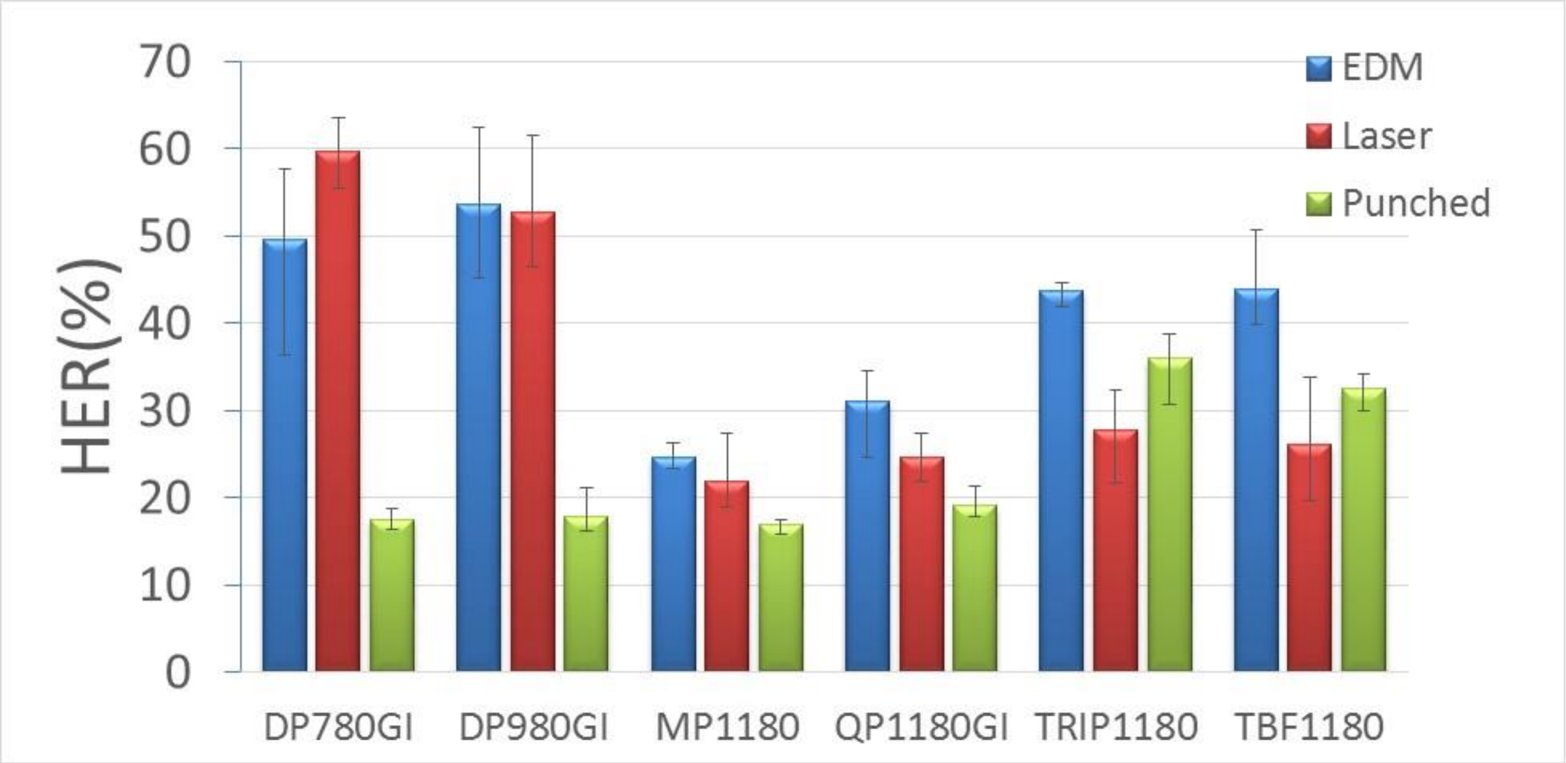
1 - Sample
2 - Binder
3 - Die
4 - Conical punch
5 - Crack on hole edge
6 - Burr from punching

Hole Expansion Test

- Mechanical properties of select grades for hole expansion testing.
- Current production DP780 and DP980 vs. newer RA-bearing 1180 MPa grades.

Type	Coating	Thickness	YS	UTS	UE	TE
TRIP 1180	Bare	1.0	888	1201	11.1	16.0
TBF 1180	Bare	1.0	902	1229	10.0	15.5
QP 1180	GI	1.2	987	1189	10.7	15.7
MP1180	Bare	1.2	916	1289	7.2	14.1
DP980 (550YS)	GI	1.2	643	1014	10.0	15.0
DP780	GI	1.1	463	833	12.9	17.0

Hole Expansion Testing



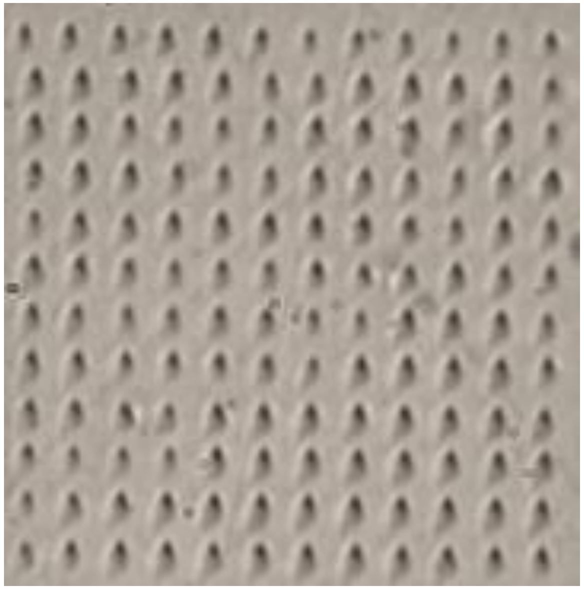
- Newer high strength 1180 MPa grades showing >= HER vs. more conventional DP steels and less sensitivity to edge condition.
- New grades need balance of global and local formability for most applications.

Nano-Indentation Evaluation – DP780

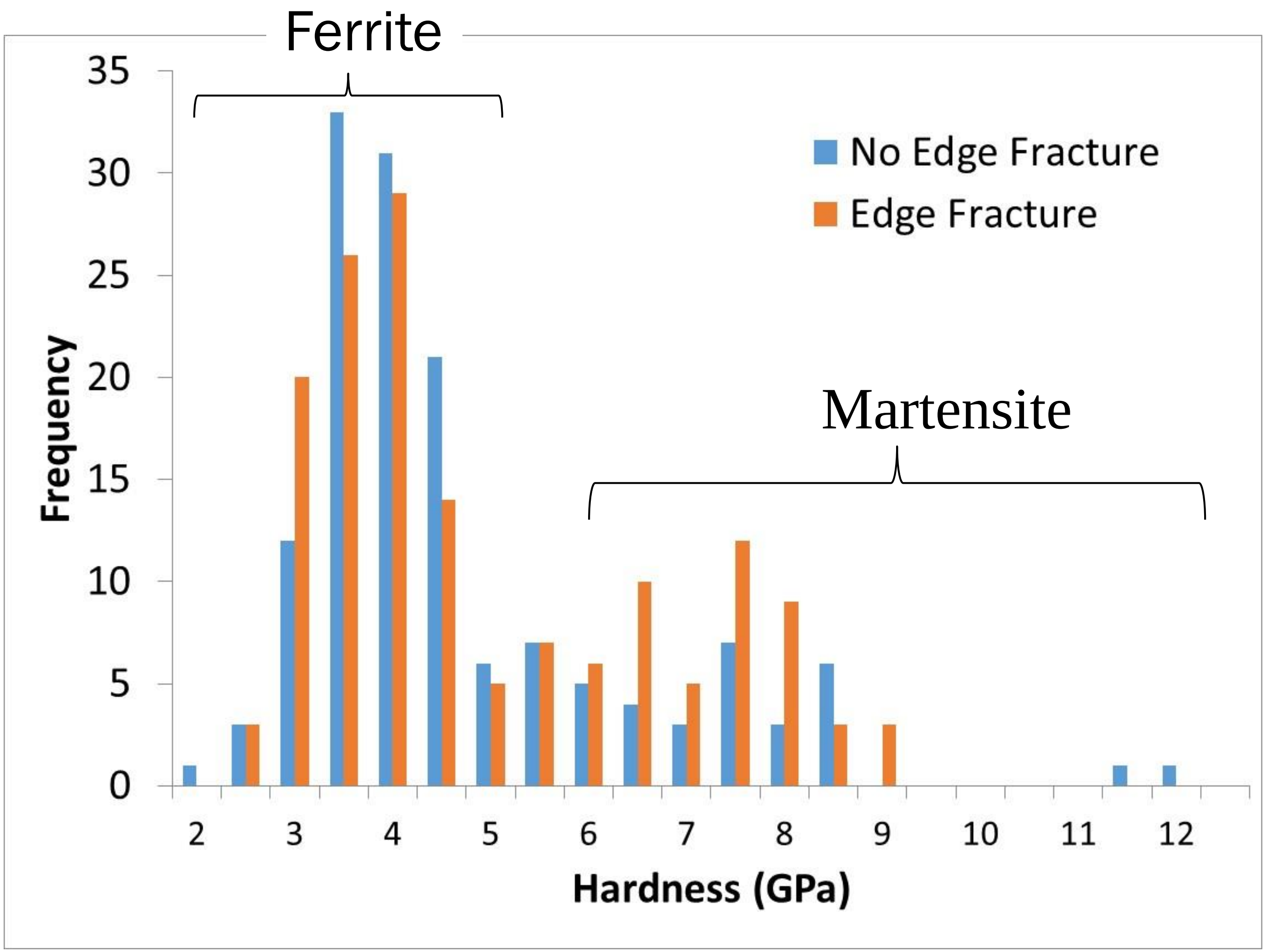
- Nano-indentation testing was performed to determine constituent hardness distributions in mixed microstructure DP780 steel.
- Two production samples were acquired representing two steel sources.
  - Under similar blanking and stamping conditions, one steel exhibited edge fracture while the other did not.
- Samples were ground/polished using standard metallurgical techniques and finish-polished with colloidal silica.

Nano-Indentation Evaluation – DP780

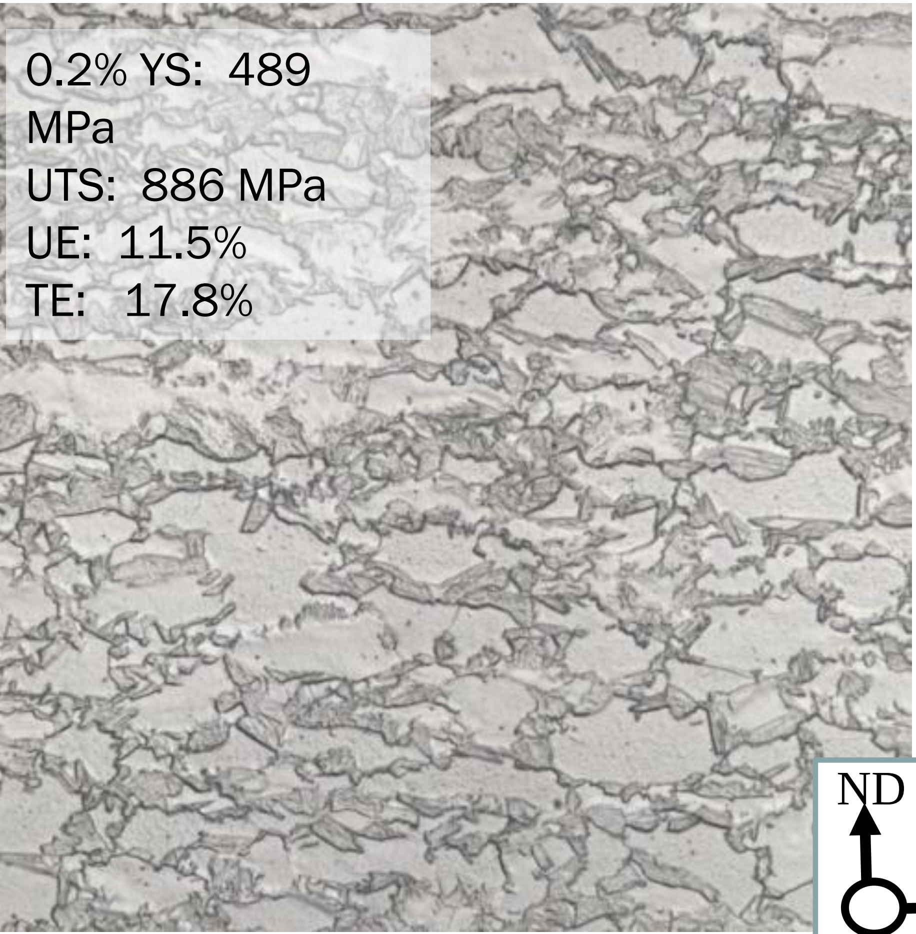
- MTS Nanoindenter XP was used.
  - Testing was performed at room temperature with a Berkovich tip
  - Displacement control was used to indent to 100 nm maximum depth
  - 12 x 12 array of indents was placed on each specimen, spaced 2 μm apart
  - Resulting hardness was averaged over a 60-90 nm depth to remove any surface abnormalities



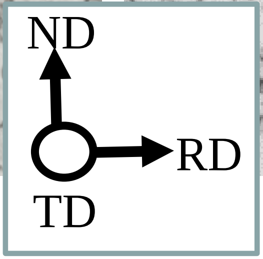
Nano-Indentation Evaluations – DP780

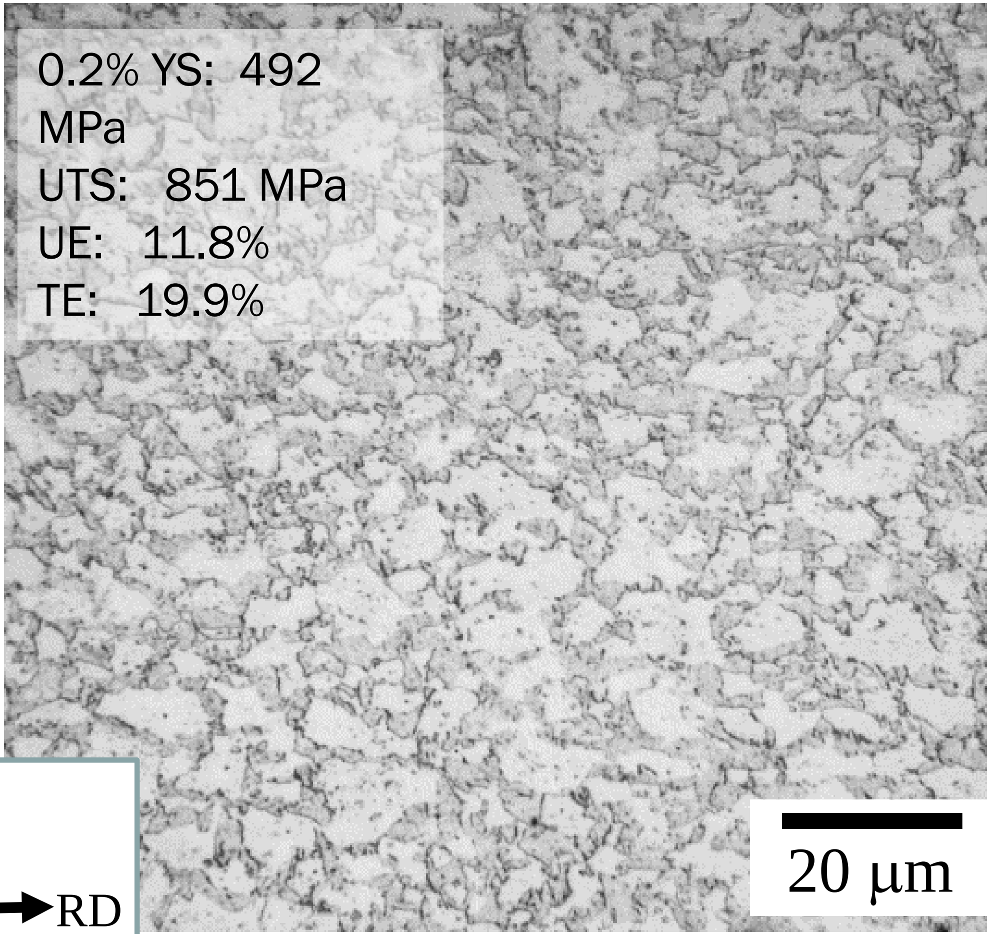


Microstructure



Edge Fractures





No Fractures

Summary

- Edge fracture susceptibility is influenced by a variety of related factors: blank edge condition, material, part design / forming (strain distribution) / trimming process.
- A balance of global and local formability performance is required for most cold-stamped parts and shall be considered in steel development.
  - Uniform, fine-grained structure required
  - Reduced hardness differential between constituents
- An industry-wide test is needed for material lot acceptance to predict edge fracture susceptibility
  - Performance not predicted by standard tensile testing

Acknowledgements

- GM Stamping Plant and Research Colleagues (Mike Lukitsch and Li Sun)

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Thank You for Your Attention!

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