Characterization of Edge Fracture in Various Types of Advanced High Strength Steel

James Dykeman, Skye Malcolm
- Honda R and D Americas, Inc.-

Gang Huang, Hong Zhu,
Naveen Ramisetti, Benda Yan, Jayanth Chintamani
- ArcelorMittal R and D, East Chicago -

Based on SAE 2011 Paper# 2011-01-1058

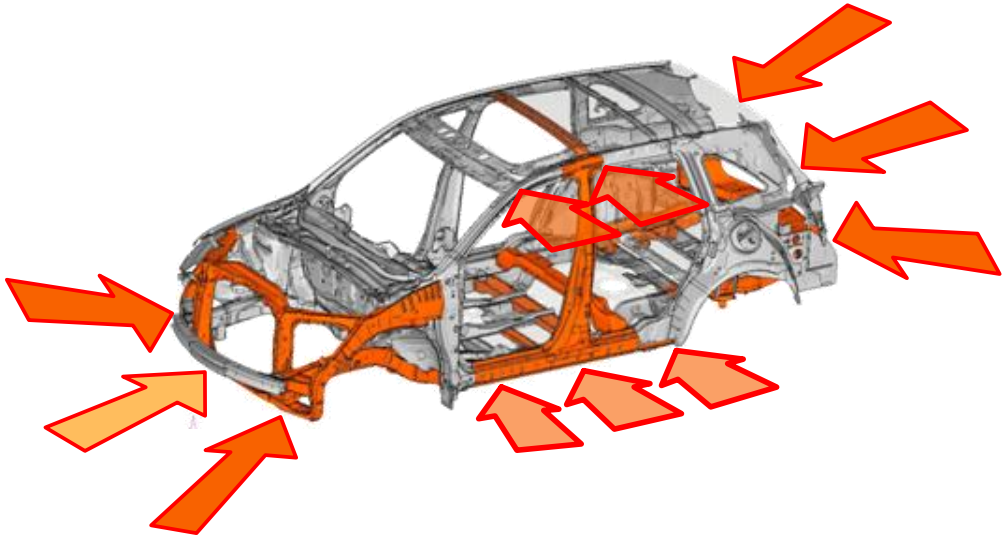
Overview

- Background - Review of Fracture Issues in AHSS
- Technical Objective and Experimental Method
- Results - Specimen Tests
- Results - Component Tests
- Material Analysis of Edge Condition
- Conclusions

Background – Review of Fracture Issues

Background

- AHSS content has rapidly increased in auto structures
  - Content is driven by need for weight reduction and crash safety.



TYPICAL VEHICLE
>30% AHSS

Dual Phase, TRIP, Complex Phase, Martensitic,…

Ex Requirements for IIHS Top Safety Pick

Frontal Crash, 1995 | Side Impact, 2003 | Rear Impact, 2004 | Roof Crush, 2010

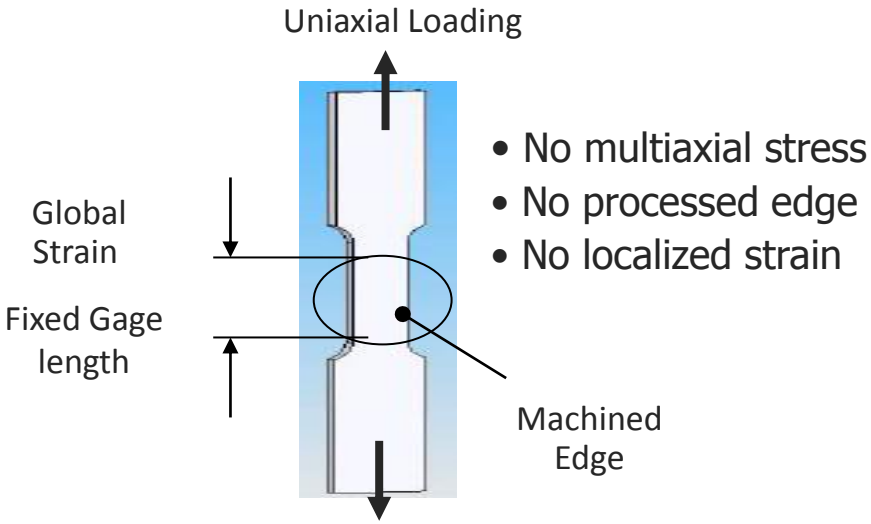
Background

- Technical Challenge - Fracture Issues in Crash Deformation
  - Previous mild steels failed by "necking or plastic instability".
  - New AHSS is more prone to fracture, particularly at edges.
  - Edge cracks on AHSS can be problematic in early vehicle development.

These type of fractures difficult to predict.

Background

- Technical Challenge - Inadequate Test Data
  - The necessary material data and simulation capability for fracture prediction does not currently exist.



- No multiaxial stress
- No processed edge
- No localized strain

Conventional tensile data has limitations for evaluating material's fracture performance.

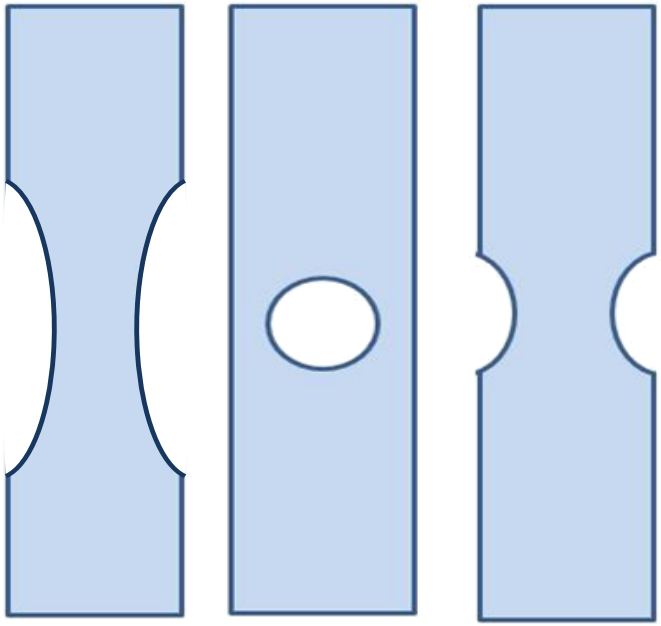
Conventional tensile data is also an inadequate input for fracture criteria and simulation models.

Need alternative test data.

Technical Objective and Experimental Method

Technical Objective / Experimental Method

- Develop New Test Specimens and Material Data
  - Alternative approach for analyzing fracture in high strength steels.
  - ➔ Tensile specimens fabricated with contrasting geometries and edge conditions.



Straight - Conventional | Center Hole | Side Notch

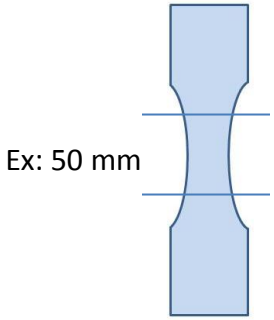
Specimen / Geometry	Edge Process
Tensile, JIS#5, JIS Z2201 W = 25 mm	Machined (fails at center)
Tensile with Center Hole W = 50, R = 10	Water Jet
	Laser
	Punched
Tensile with Side Notch W = 50, D = 20	Water Jet
	Laser
	Punched

- Different stress/strain states -

Experimental Method

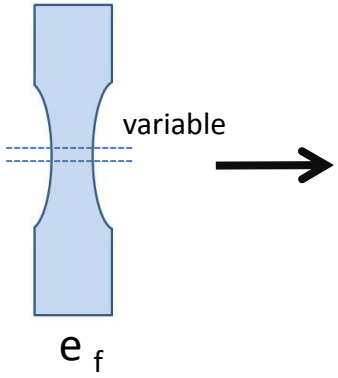
- Strain Measurement Method
  - Localized strain measure by Digital Image Correlation (DIC)

Conventional

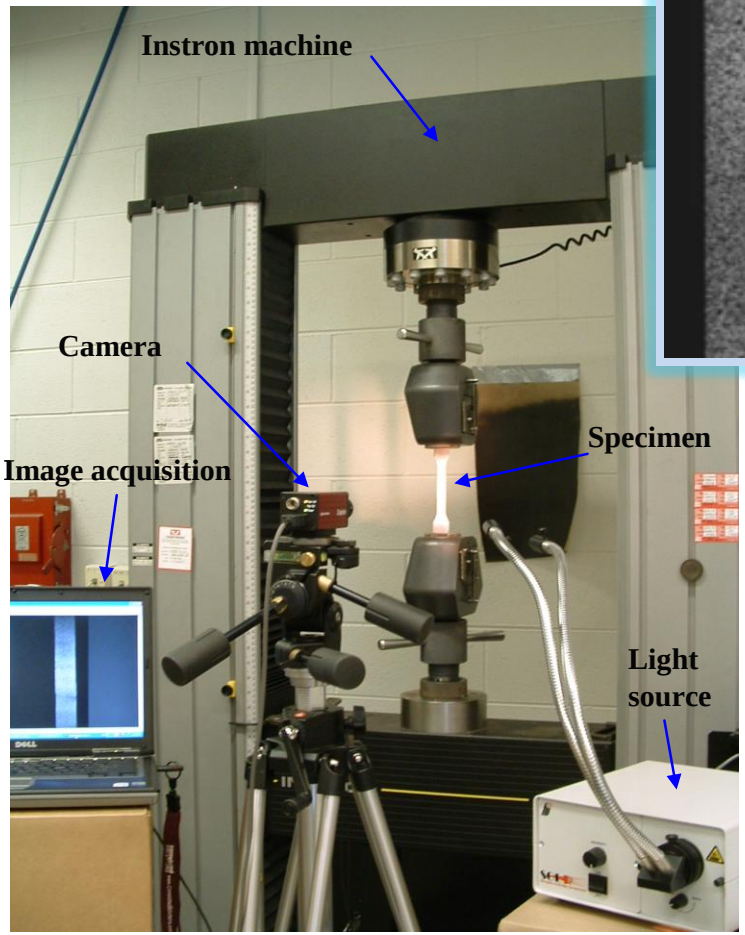


- Extensometer
- Contact
- Fixed gage length

Localized IDIC)



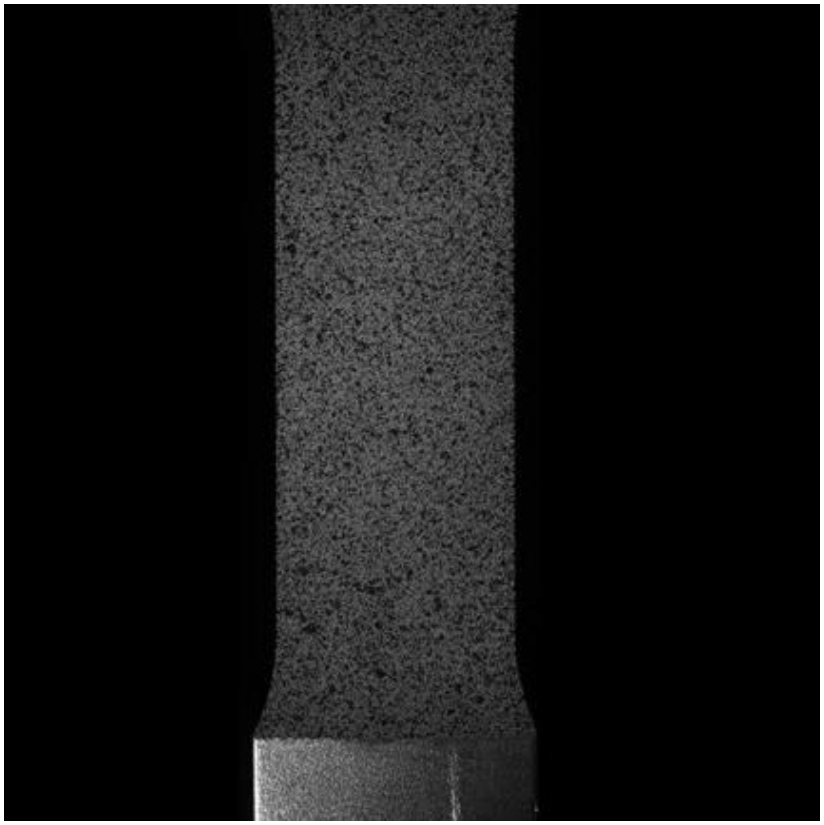
- Digital Video
- Non-contact
- Variable gage length.

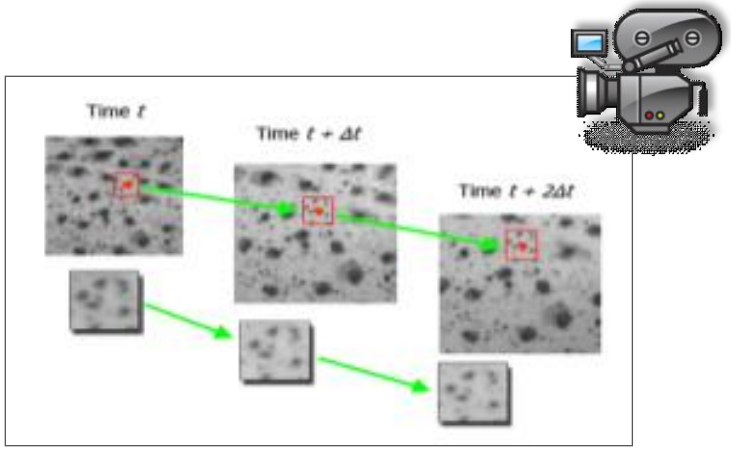


New strain measurement techniques were used in the evaluation of the test specimens.

Experimental Method

- Strain Measurement Method
  - Example tensile test with DIC speckle pattern.

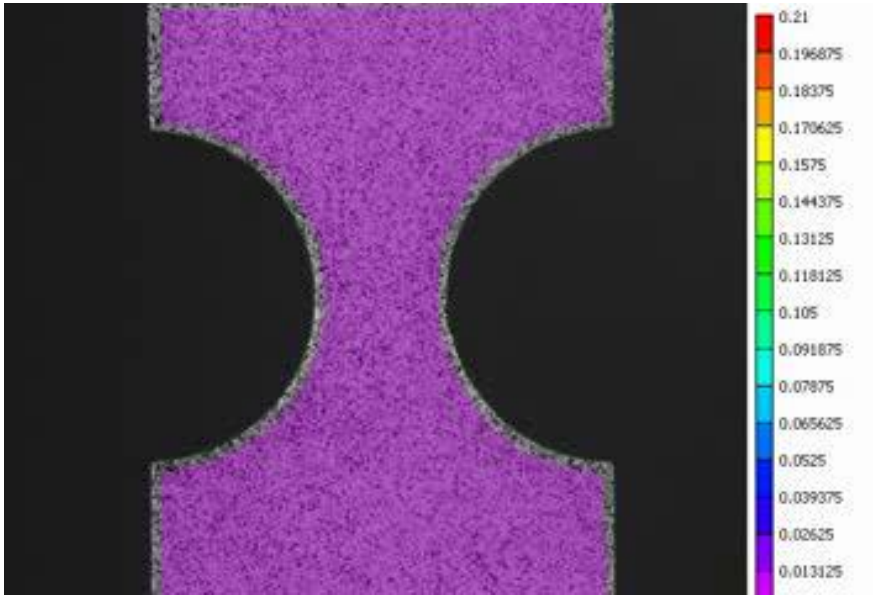


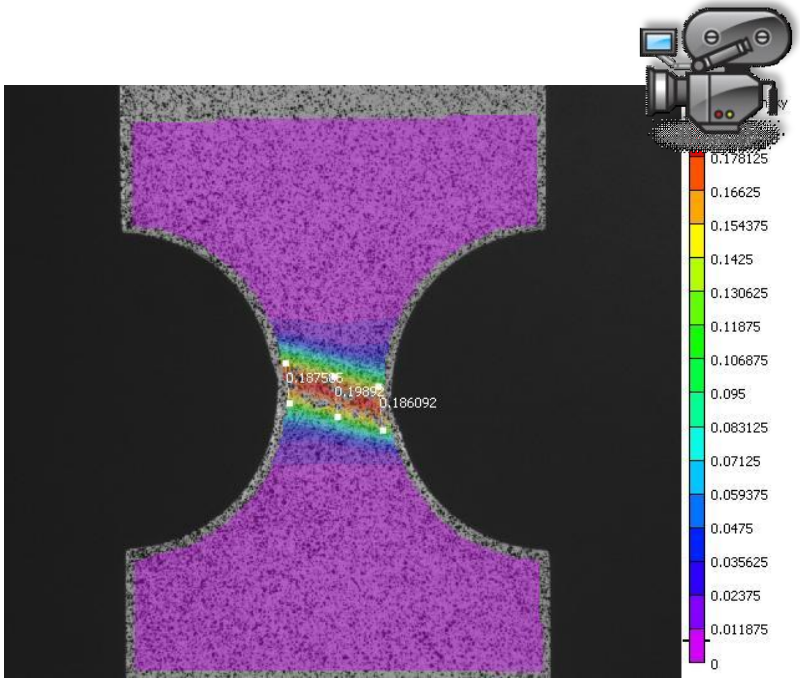


↑ Software measures displacement of speckle pattern to calculate strain.

Experimental Method

- Strain Measurement Method
  - Localized strain measured by Digital Image Correlation software.

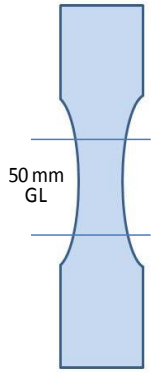




Experimental Method

- Selected Test Materials
  - C-Mn, Dual Phase, TRIP, and Martensitic (Hot Stamp)

Materials	TYPE	Yield Stress (MPa)	Tensile Strength (MPa)	Total Elongation (%)	notes
JAC 590R	C-Mn	501	618	22.1	High Yield/Tensile ratio
JAC 780T	TRIP	502	876	21.3	High n value, elongation
JSC 980Y Low Carbon	Dual Phase	687	1043	13.4	Good strength + TE balance
JSC 980Y Mid Carbon	Dual Phase	689	1072	14.2	Good strength + TE balance
JAC 980Y Low Carbon	Dual Phase	676	1025	14.2	Good strength + TE balance
JAC 980Y Mid Carbon	Dual Phase	646	1035	14.5	Good strength + TE balance
Hot Stamp 1500 (Usibor)	Martensitic	983	1497	6.6	Very High Strength

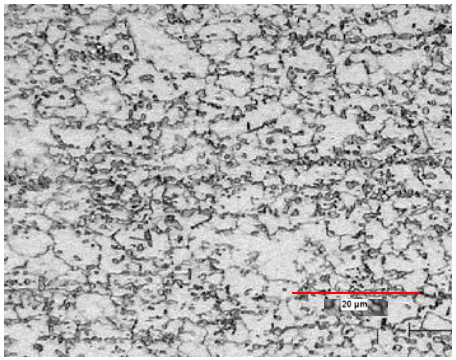


Conventional
JIS #5

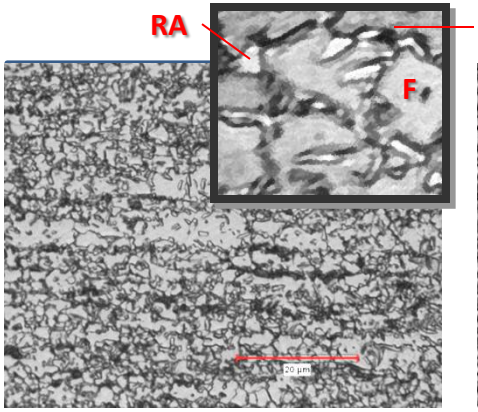
- Seven different high strength steels (t = 1.4 mm) were selected.
- Conventional data is shown based on JIS #5, 50 mm GL.

Experimental Method

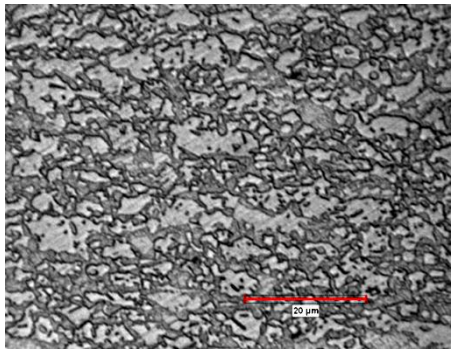
- Selected Test Materials
  - C-Mn, Dual Phase, TRIP, and Martensitic (Hot Stamp)



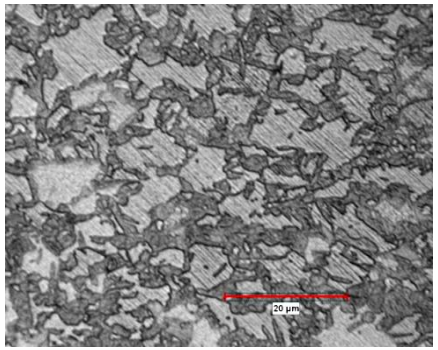
JAC 590R
General structural material



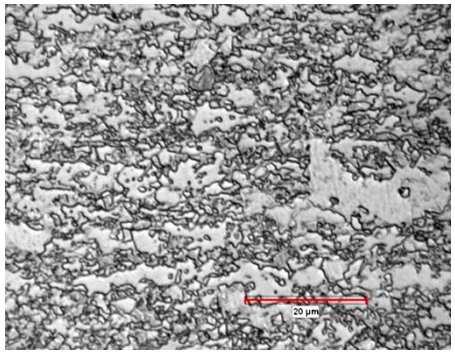
JAC 780T (TRIP)
Intrusion and absorption - Side sill, B Pillar, Rails



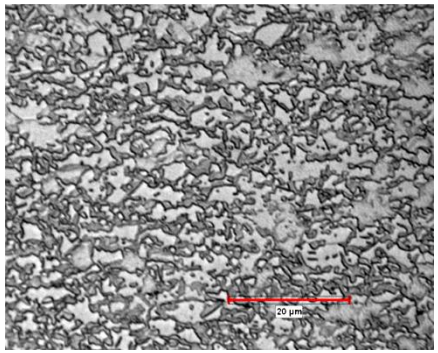
JSC 980Y Low Carbon
Upper body Intrusion Parts – B pillar Rfct and inner



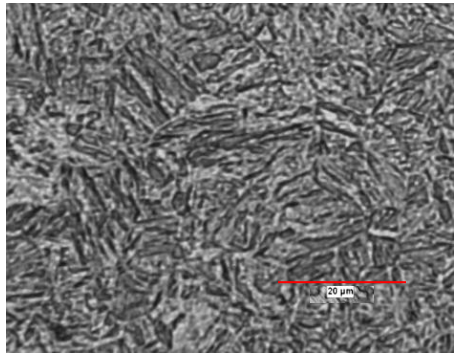
JSC 980Y Mid Carbon (DF 140)
Bumpers



JAC 980Y Low Carbon
Lower body intrusion parts – ex Sill



JAC 980Y Mid Carbon
Lower body intrusion parts – ex Sill



USIBOR 1500
Intrusion and roof crush - B pillar, sill, upper rail

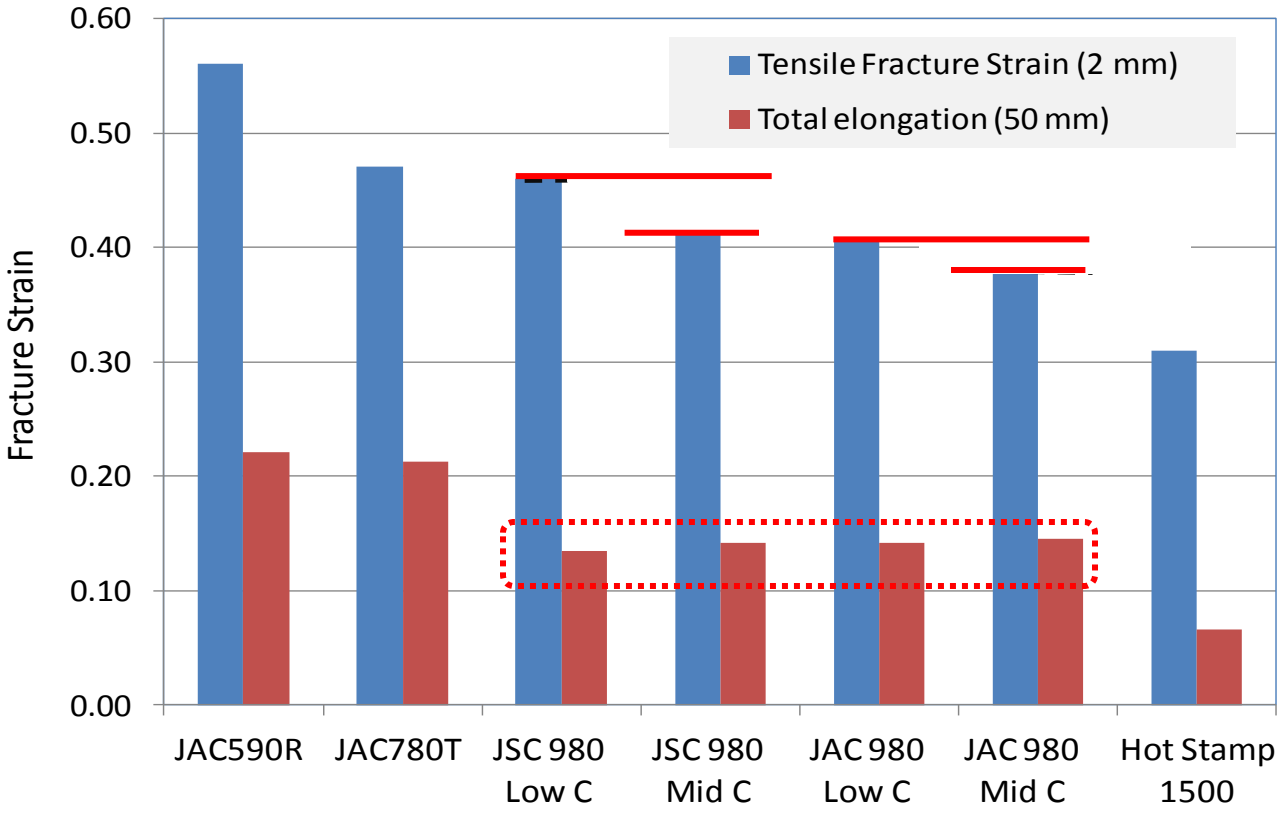
C-Mn Steel (R)
Ferrite (grey)
Bainite, Pearlite (dark)
TRIP Steel (T):
Ferrite (grey),
Bainite (dark),
Retained austenite (white)
Dual phase grades (Y):
Ferrite (light)
Martensite (dark)
USIBOR
all Martensitie (dark)

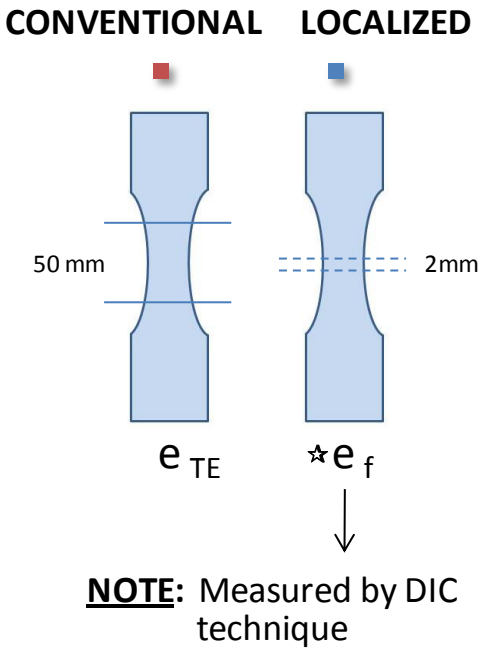
Test Results – Specimens

1. Effect of Localized Strain
2. Effect of Stress State
3. Effect of Edge Condition

Specimen Test Results

- Effect of Localized Strain

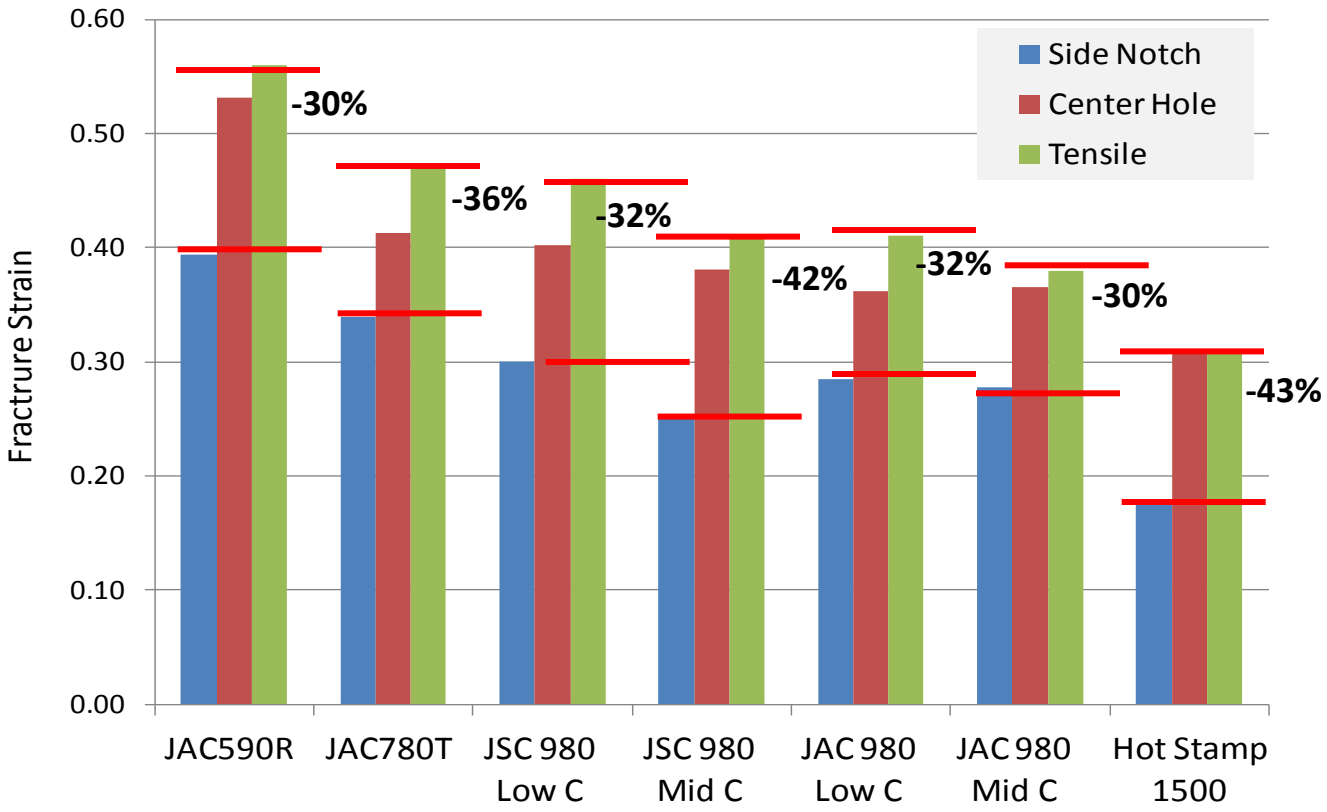


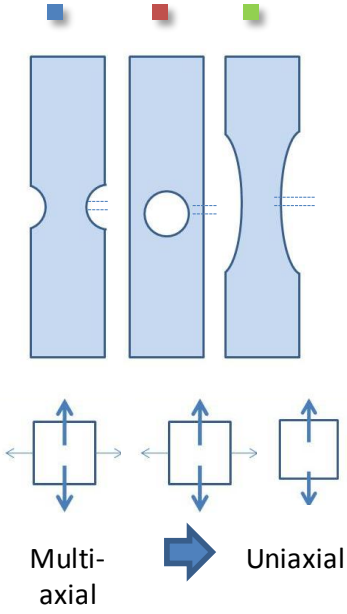


- Conventional Tensile Elongation (e_{TE}) and Fracture Strain (e_f) are shown to be two distinct measurements,… 980 grades have little difference in TE, but notable difference in fracture strain.

Specimen Test Results

- Effect of Stress State



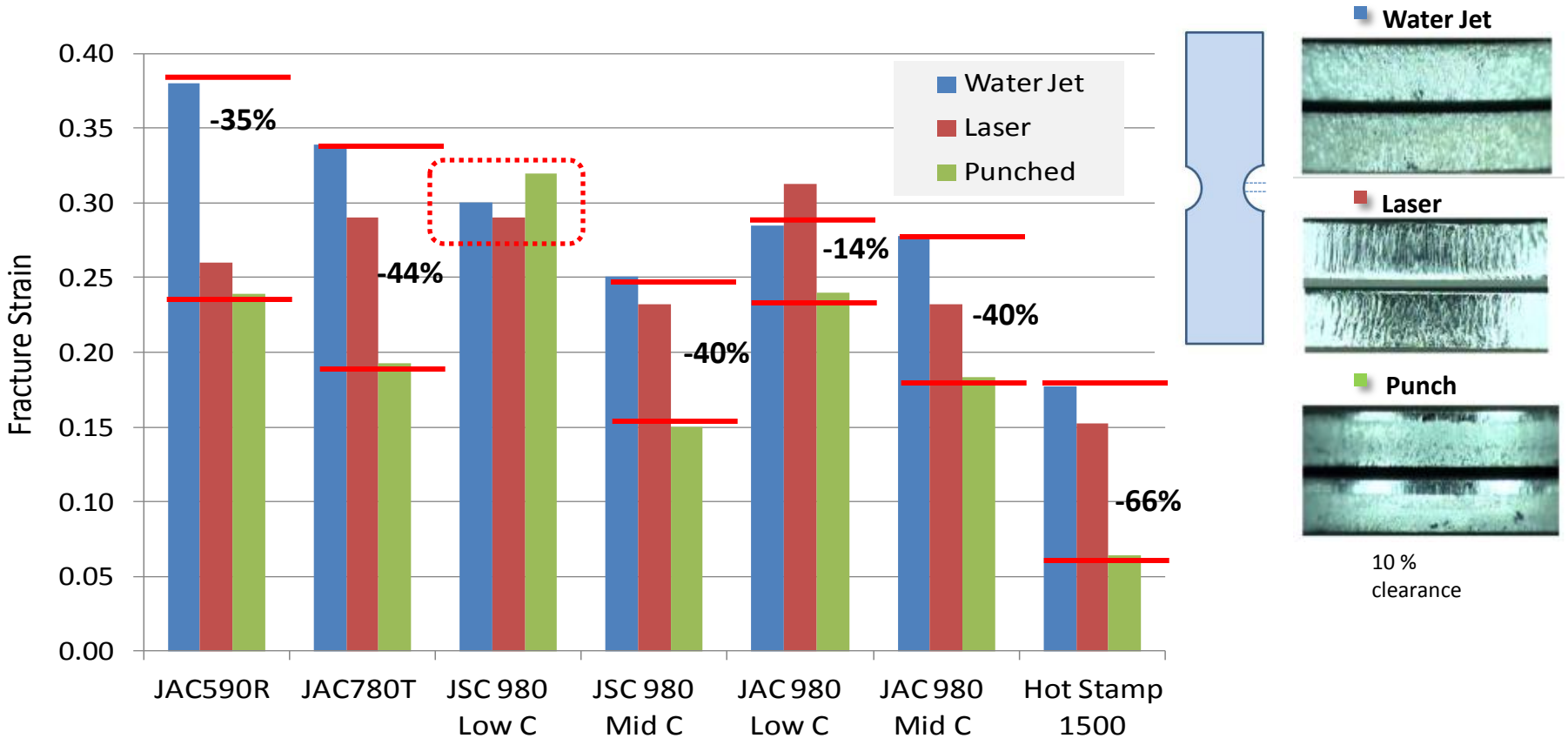


Water jet edges for hole and notch specimen

- Fracture Strain is dependent on stress state of specimen.
- There is 30 - 43% strain difference between notch and uniaxial.

Specimen Test Results

- Effect of Edge Condition



- Punching and laser cut reduces fracture strain of material.
- 590R, 780T, HS 1500, and 980 Mid C show sensitivity to punching.
- Other grades such as 980 Low Carbons were less sensitive.

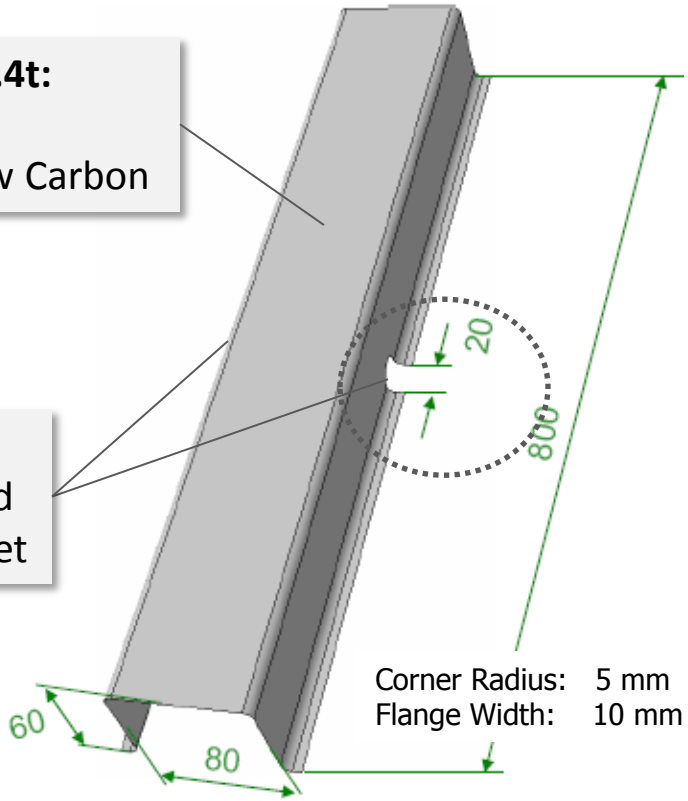
Test Results - Components

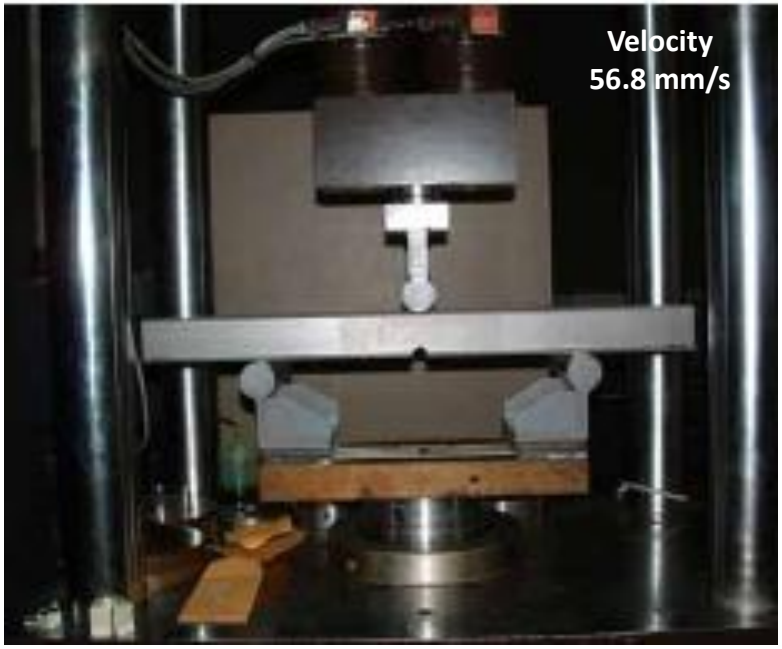
Component Test Results

- Hat Section with Side Notch
  - **Test Set-up:**

Materials, 1.4t:
JAC 780T
JSC 980Y Low Carbon

Edge:
Punched
Water Jet

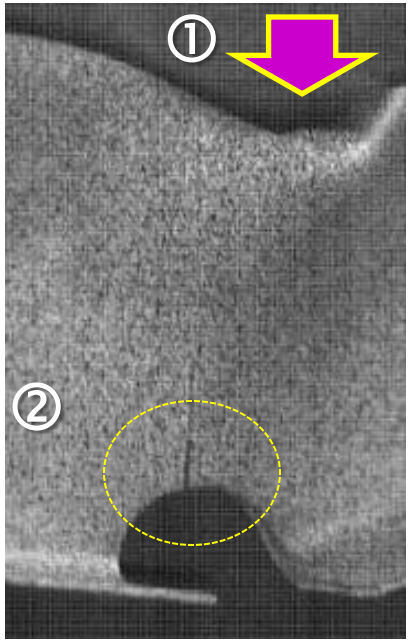


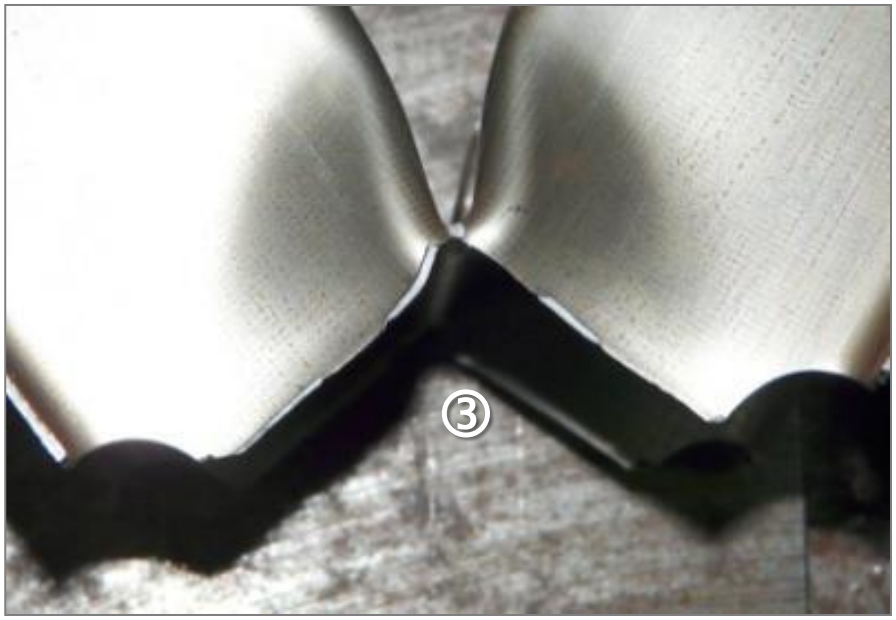


- Hat Sections with side notches were tested in bend crush mode.
- Two Materials and two edge conditions were included.
- DIC was used for strain measurement.

Component Test Results

- Hat Section with Side Notch
  - Failure Sequence of Hat Section during deformation

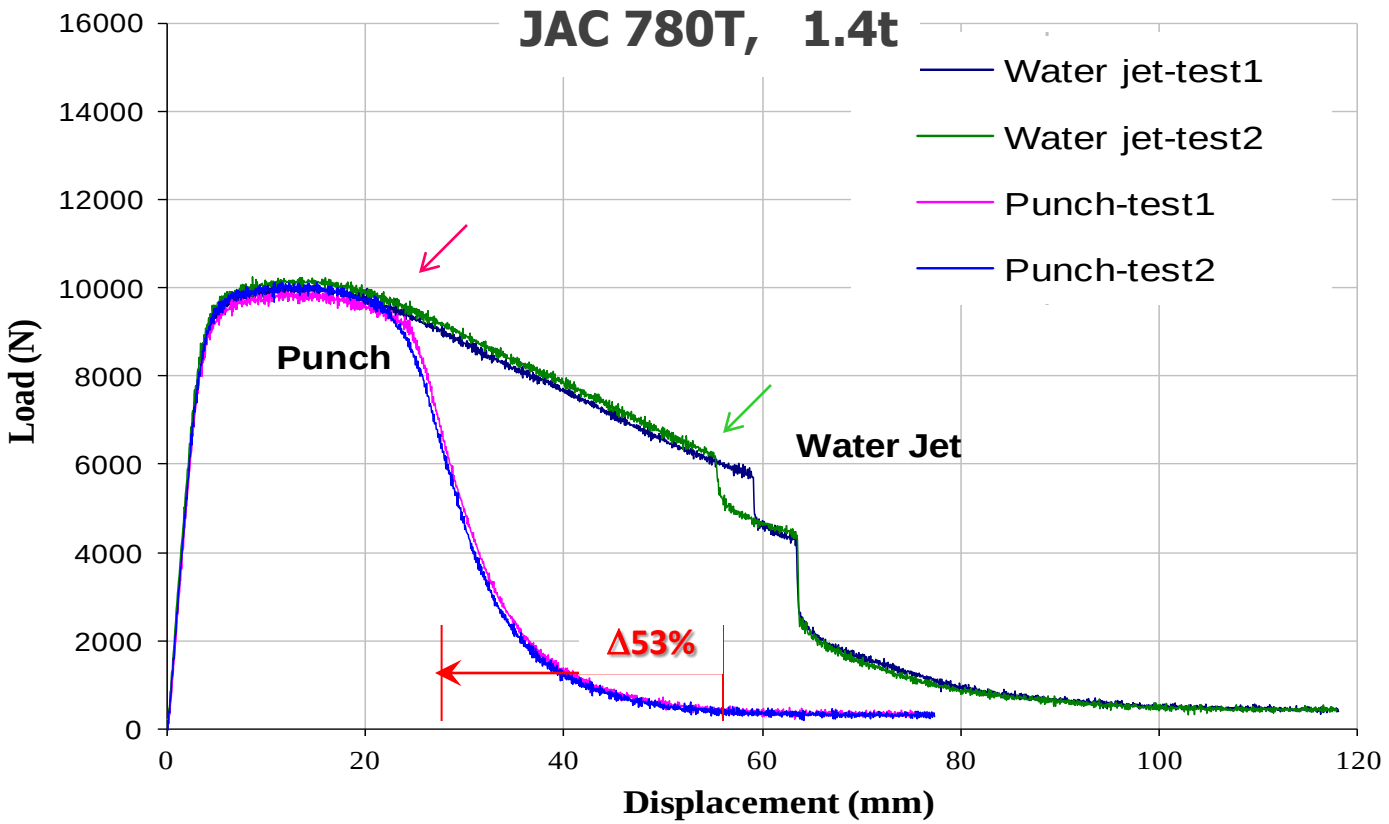




1. Components experience buckling on top of hat section.
2. Fracture at the notch subsequently occurs.
3. Cracking progresses up through the sidewall of section.

Component Test Results

- Hat Section with Side Notch



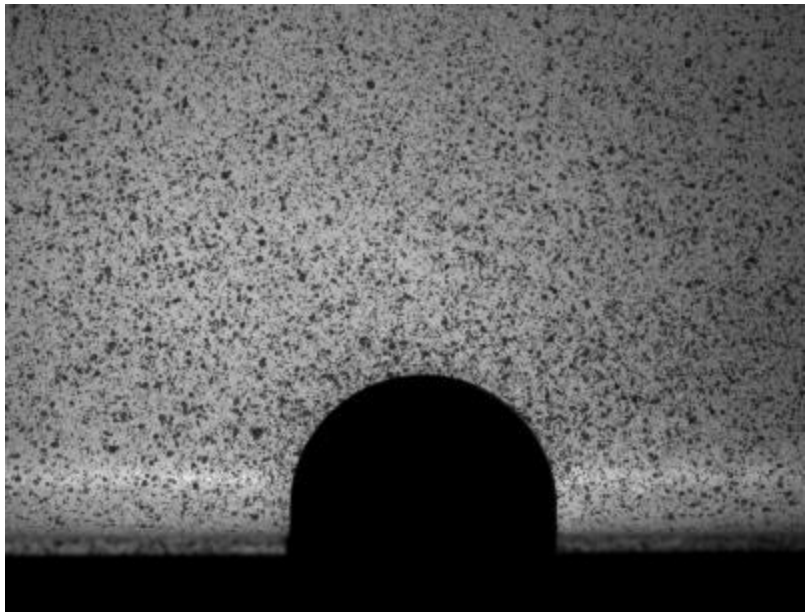
- The 780T material achieves high displacement with water jet.
- However, reaches a much lower displacement with punched edge.
- Similar effect was observed on side notch test samples.

Component Test Results

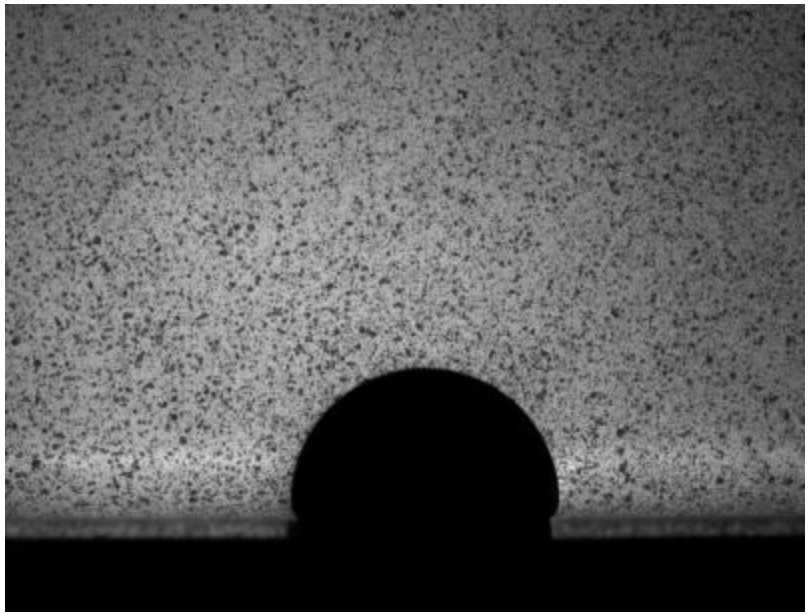
- Hat Section with Side Notch

JAC 780T, 1.4t

Water Jet



Punch

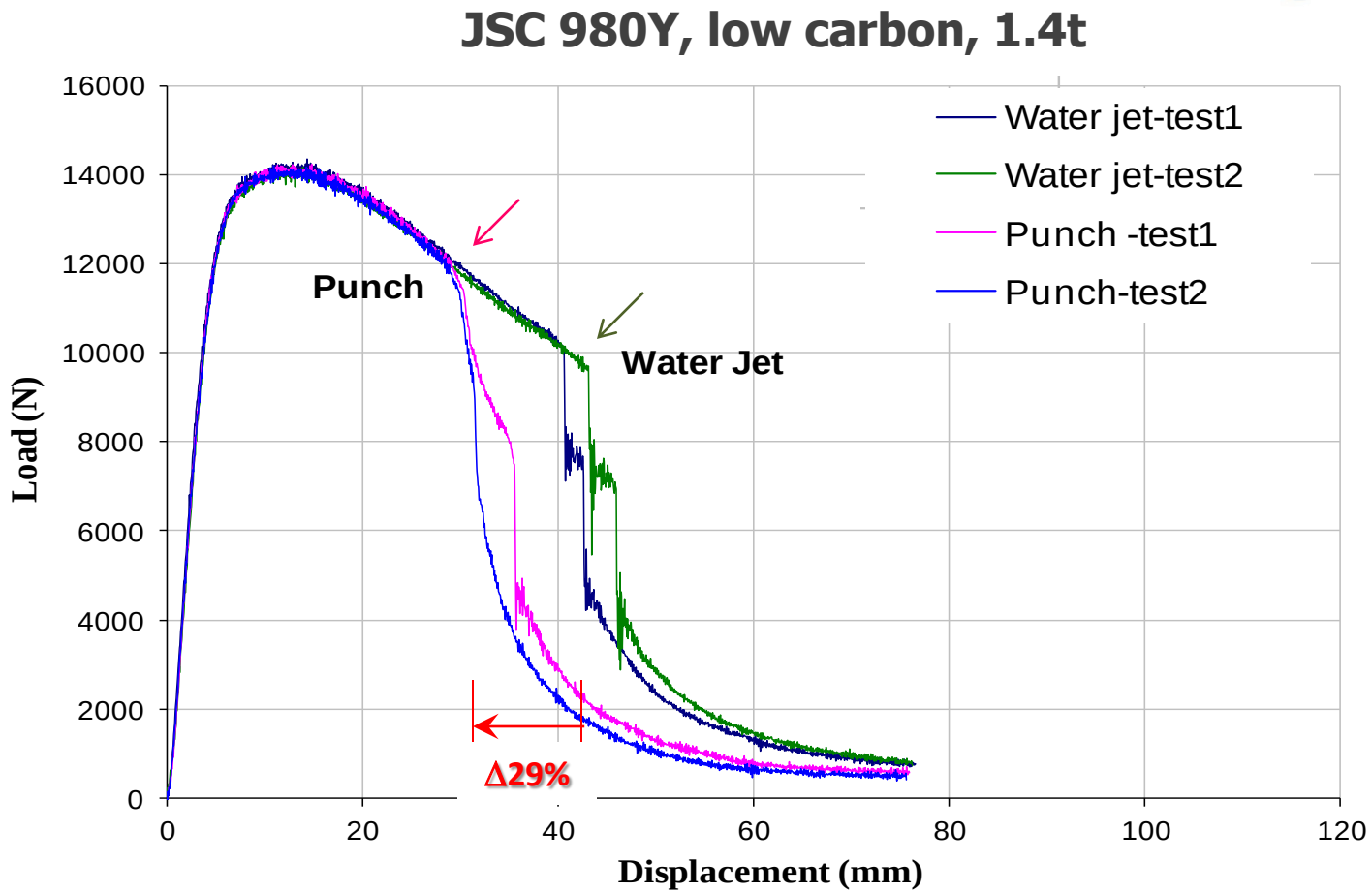


Fracture Strain - Water Jet	Fracture Strain - Punch
0.38	0.20

Punching had a significant effect on 780T fracture behavior.

Component Test Results

- Hat Section with Side Notch



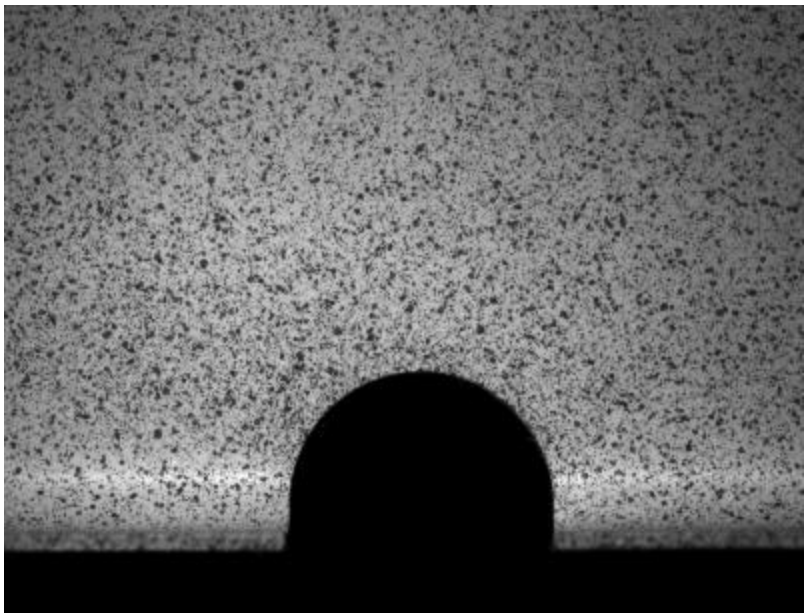
- In contrast, punching has less effect on JSC 980Y fracture behavior,…Similar effect was observed on side notch test samples.

Component Test Results

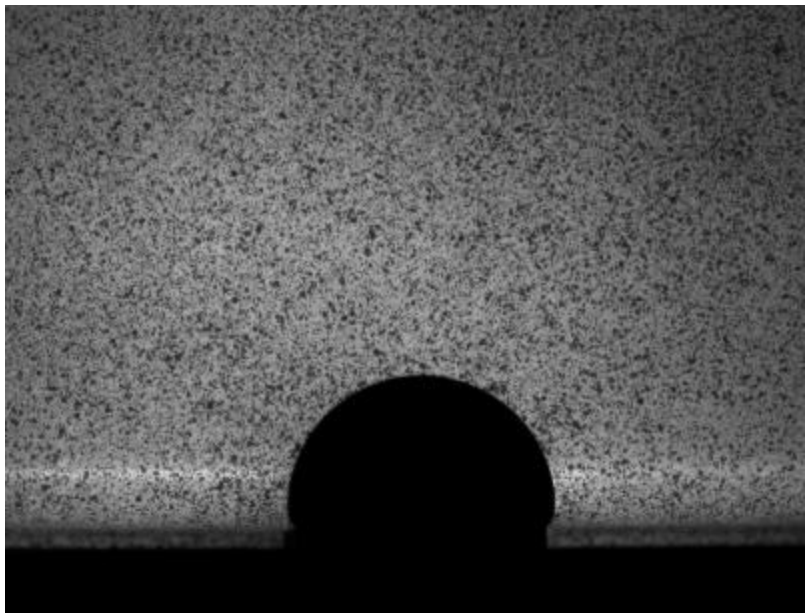
- Hat Section with Side Notch

JSC 980Y, low carbon, 1.4t

Water Jet



Punch



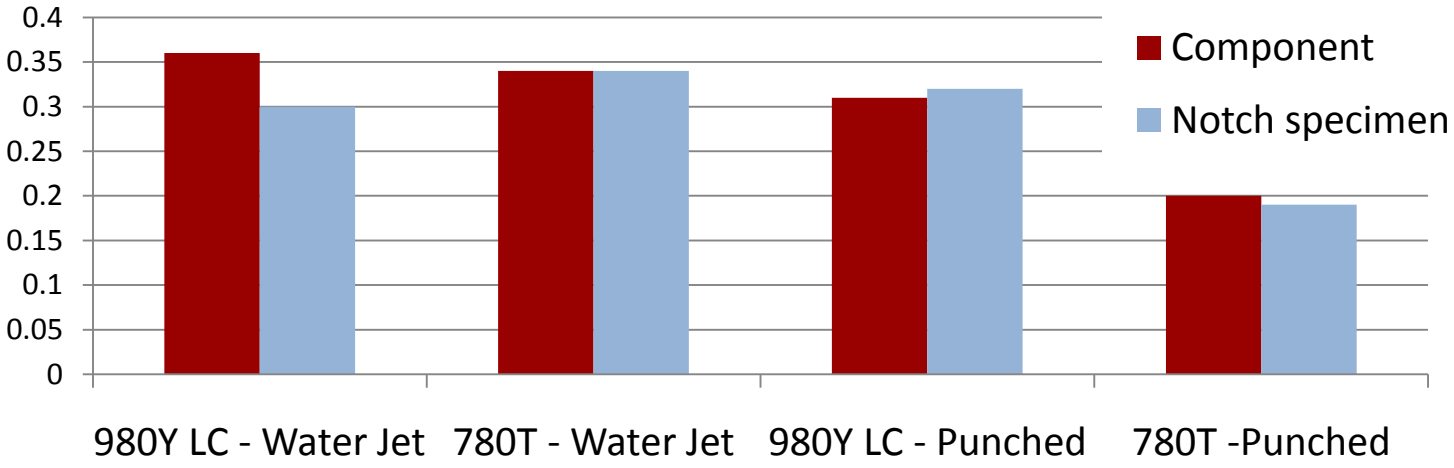
Fracture Strain - Water Jet	Fracture Strain - Punch
.35	.33

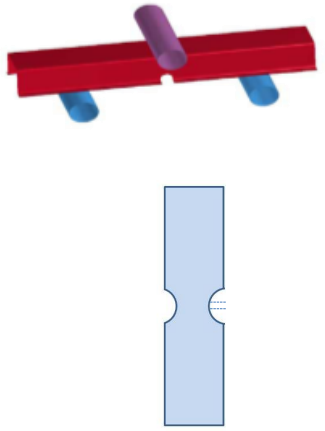
Punching had less effect on JSC 980Y fracture behavior

Component Test Results

- Hat Section with Side Notch

Steel	Average Fracture Strain (Major)			
	Water jet		Punched	
	Component	Notch specimen	Component	Notch specimen
JSC 980Y - low C	0.36	0.30	0.31	0.32
JAC780T	0.34	0.34	0.20	0.19





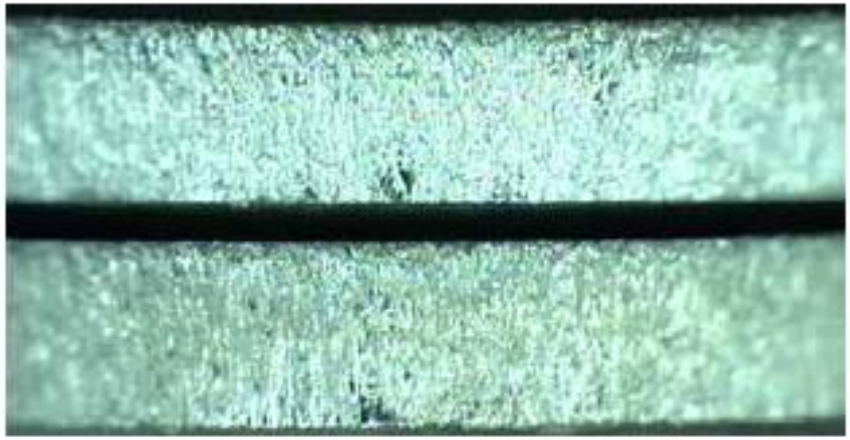
Fracture Strains for Component Test versus Lab Test Specimen.
(2 mm gage length, DIC).

Material Analysis of Different Edge Conditions

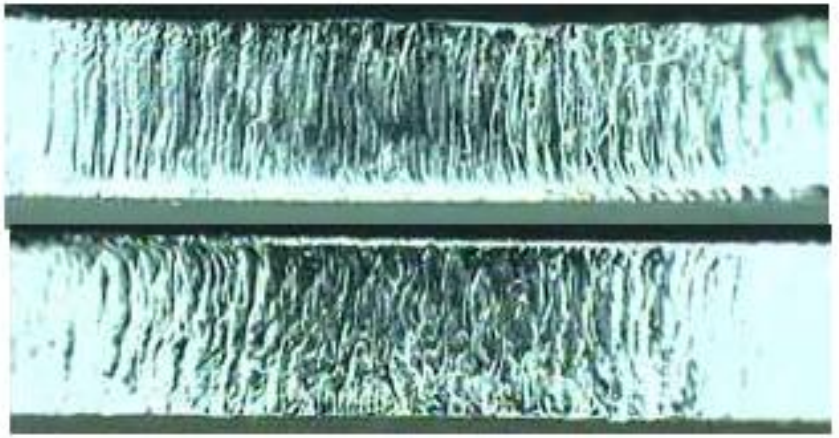
Material Analysis of Edge Condition

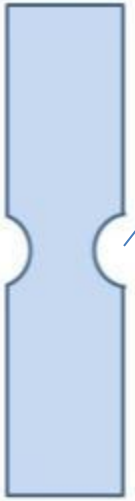
- Edge Condition

WATER JET - just used for prototypes



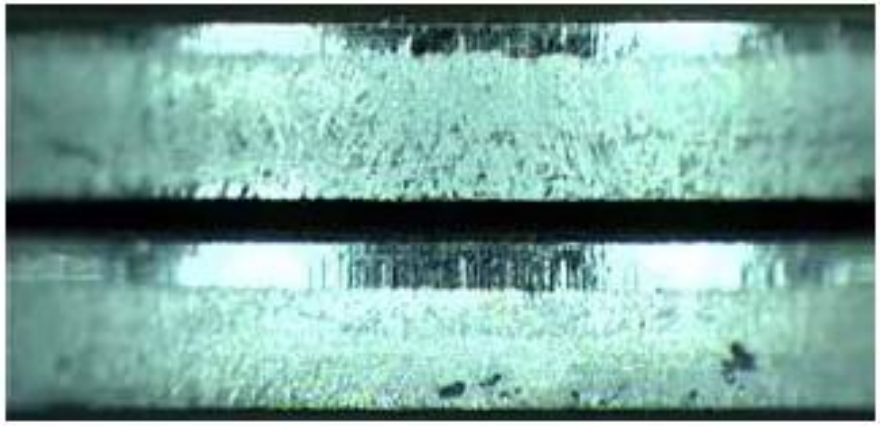
LASER - used for hot stamp production





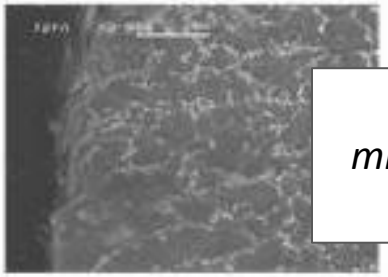
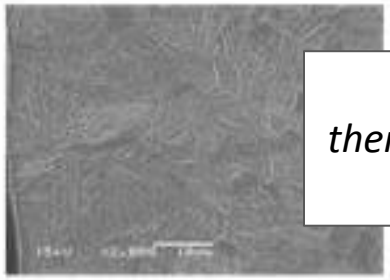
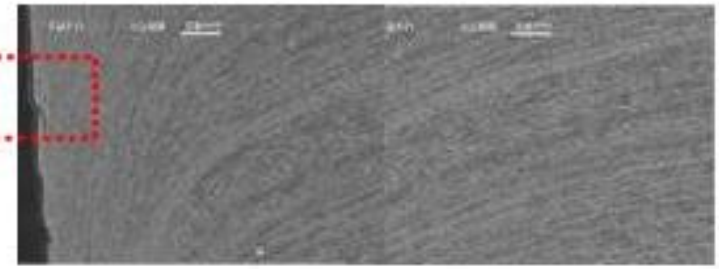
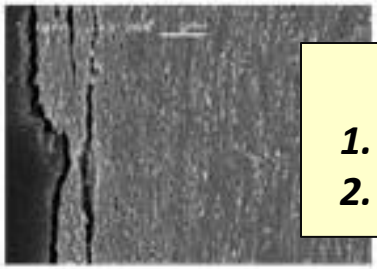
- WATER JET
- LASER
- PUNCH

PUNCH - typical process for stamped parts



Material Analysis of Edge Condition

- Edge Condition

Cutting Method	Edge Overview	Near Edge
Water Jet 590R		
Laser 590R		
Punch 590R		

WATER JET
minimal damage
< 5um

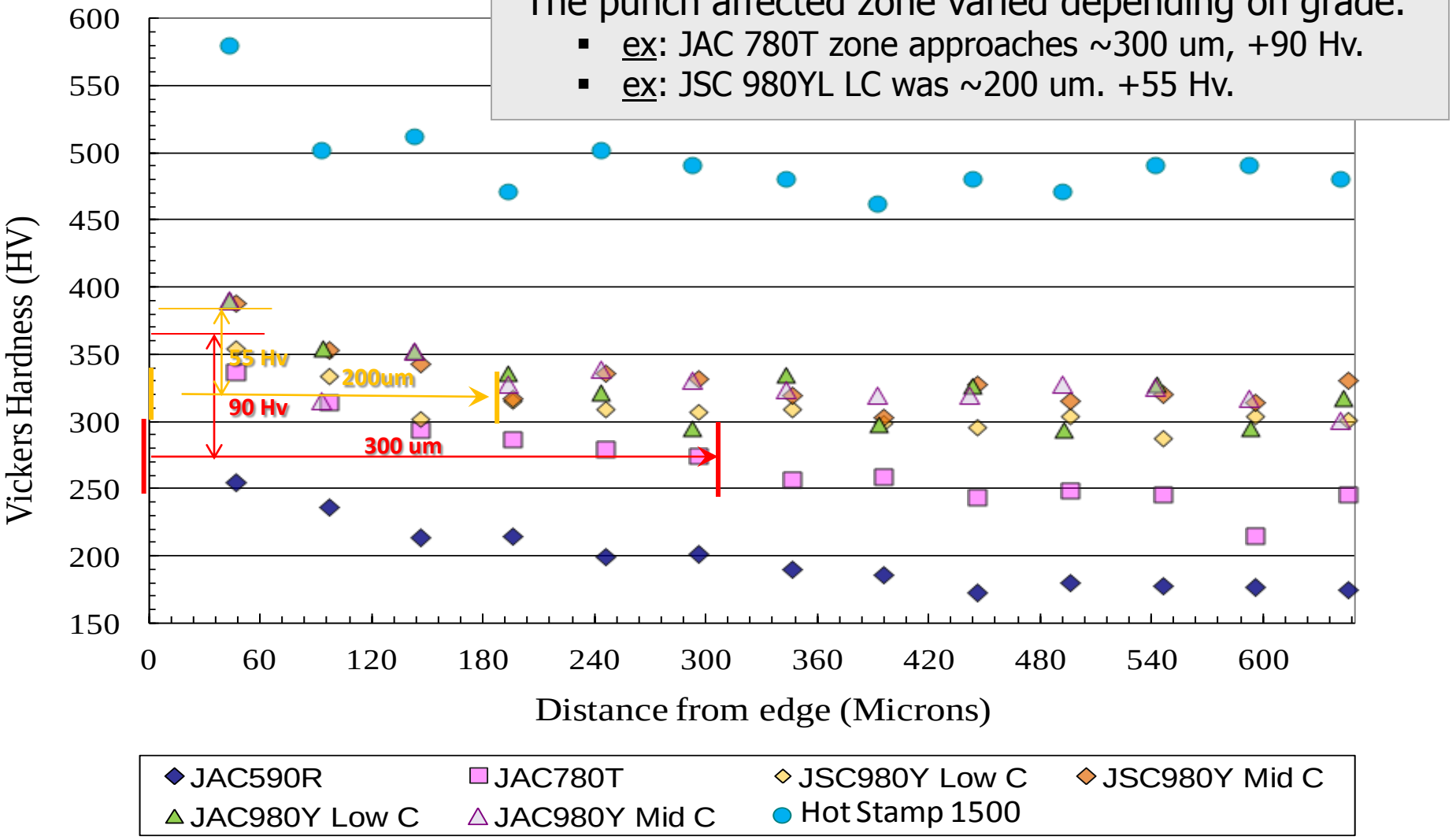
LASER
thermal hardening
~ 200 um

PUNCH
1. work hardening
2. micro cracks

Material Analysis of Edge Condition

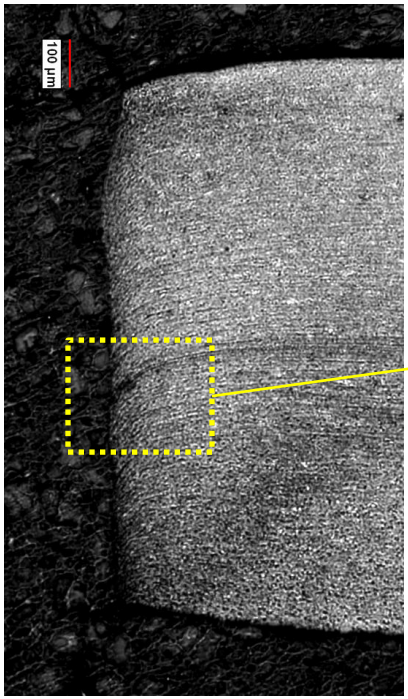
- Punched Edge Damage – Work Hardening

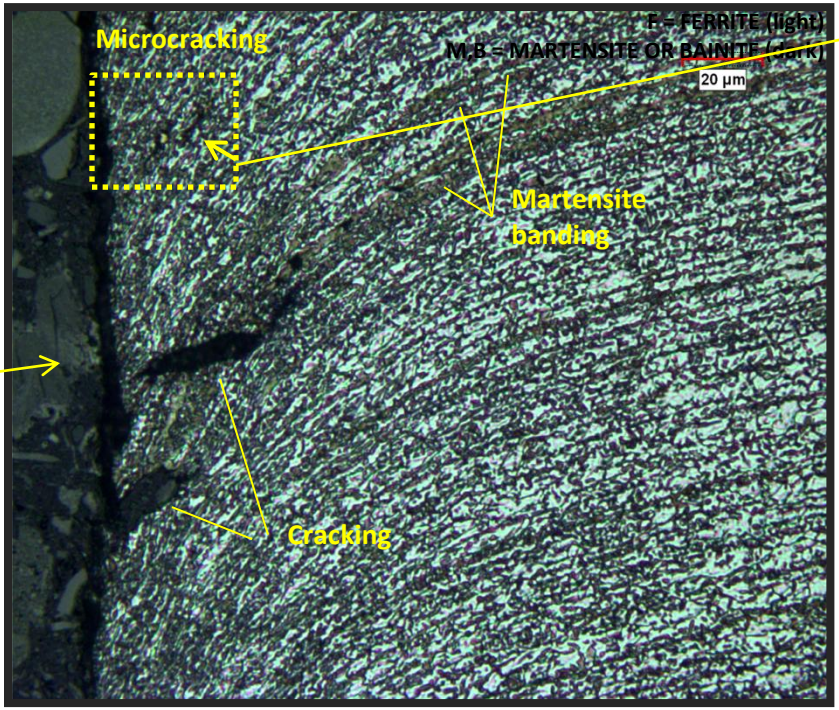
The punch affected zone varied depending on grade.
- ex: JAC 780T zone approaches ~300 um, +90 Hv.
- ex: JSC 980YL LC was ~200 um. +55 Hv.

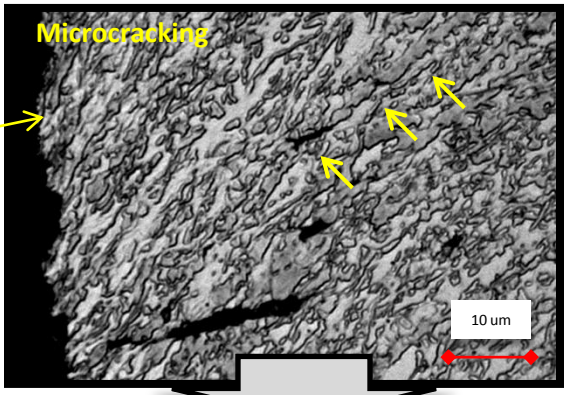


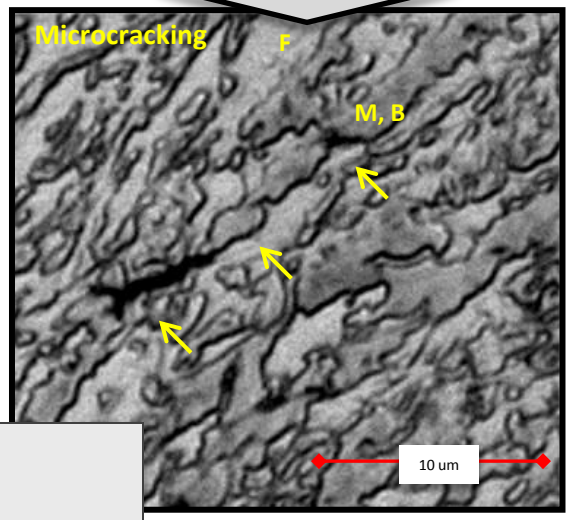
Material Analysis of Edge Condition

- Punched Edge Damage – Microcracks

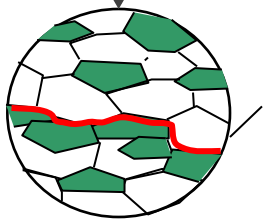








- Every material had some cracks/voids. (ex: 780T)
- General Theory - Multi-phase steels fail at phase interfaces.
  - ➔ TRIP: Conversion of retained austenite is suspected to aggravate this condition.
  - ➔ DP: Lower phase hardness differential believed to help reduce cracking tendency. (ex: 980Y LC)



Cracking at interface between hard Martensite and soft Ferrite

Conclusions

1. Fracture strains in AHSS are dependant on stress state, edge condition, and selected gage length.

2. A "plane strain" or "notched" state of stress reduces a materials fracture stain relative to a uniaxial state of stress.

3. Edge processing with punch or laser degrades the fracture strain limit at edges relative to a non damaged edge (such as water jet).

4. Certain materials exhibited a high "punch" sensitivity:
   - 780T punched fracture strain was 44% lower relative to water jet.
   - 1500 Hot stamp punched fracture strain was 66% lower than water jet condition.

5. Dual phase 980 steels based on a low carbon composition showed a reduced sensitivity to punch damage relative to the mid carbon versions.