GREAT DESIGNS IN STEEL

A NEW TESTING METHOD FOR EVALUATING EDGE CRACKING OF AHSS

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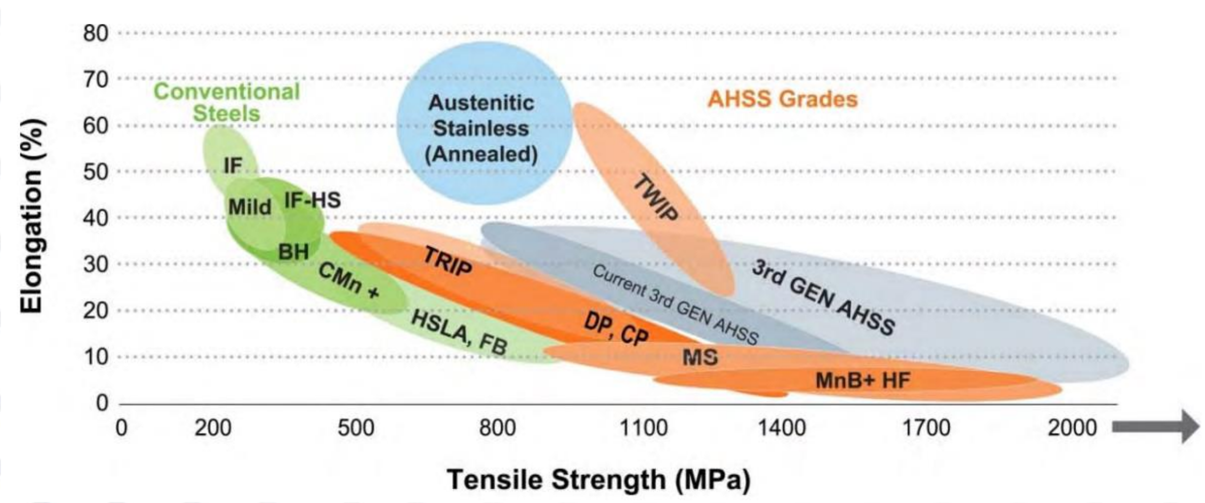
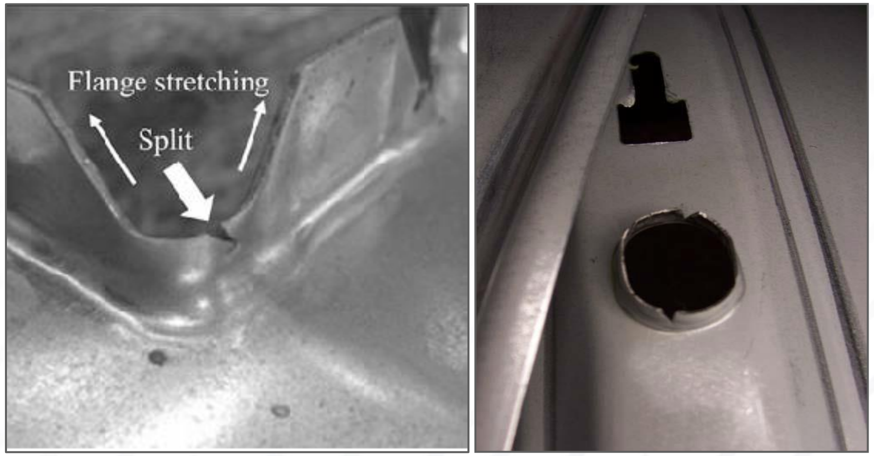
BACKGROUND

- The supplier-to-supplier or batch-to-batch variations of the material properties for the same grade steel exist in advanced high-strength steel (AHSS).
- This variation along with edge quality from blank processing can significantly influence the local formability that can lead to edge formability differences.

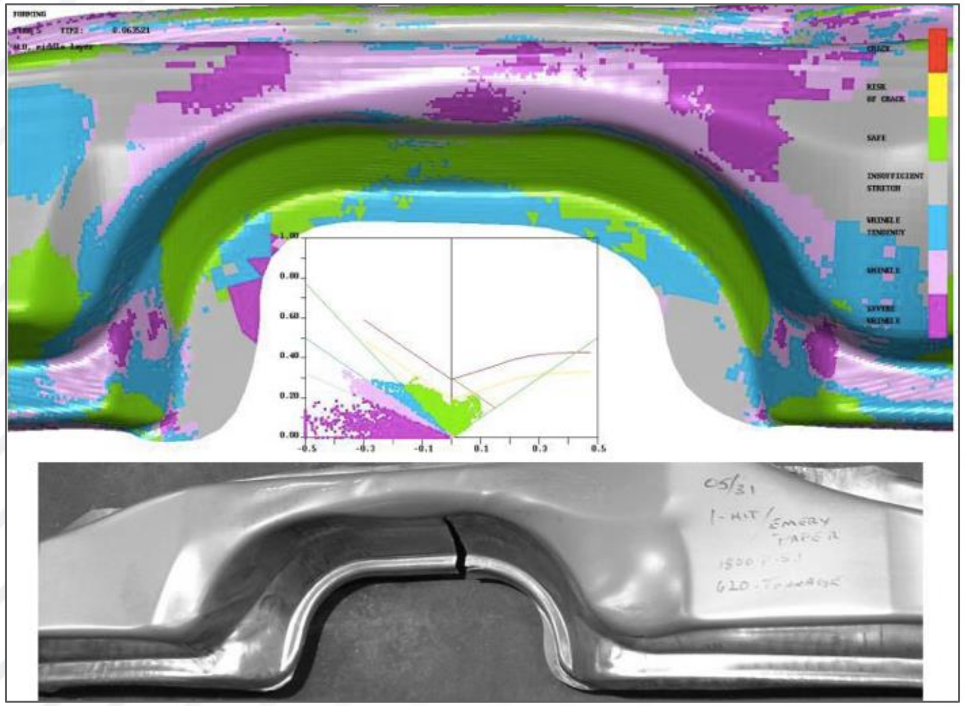


Steel Strength-Ductility Diagram
(Courtesy of World Auto Steel)

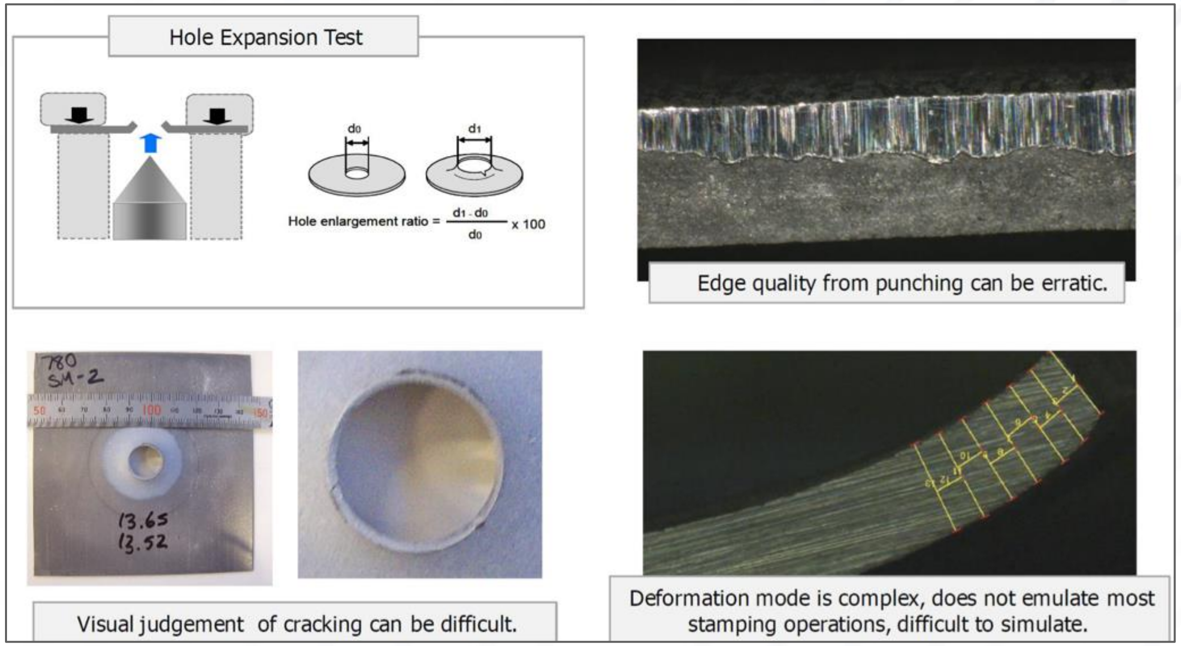


Stretch Flanging (Courtesy of Honda)

BACKGROUND – PREDICTION AND EXPERIMENTAL EVALUATION



(Chen and Zhou, 2008)



(Dykeman, 2016)

- Edge cracking is difficult to predict, as well as to accurately evaluate.
- Discrepancy is observed between finite element analysis (FEA) and the actual stamping process.

- The current ISO standard for edge quality evaluation cannot relate edge condition and failure mode in actual production.

OBJECTIVES & EXPECTED BENEFITS

- Develop and validate a new test method to evaluate the sheared edge formability considering the production conditions

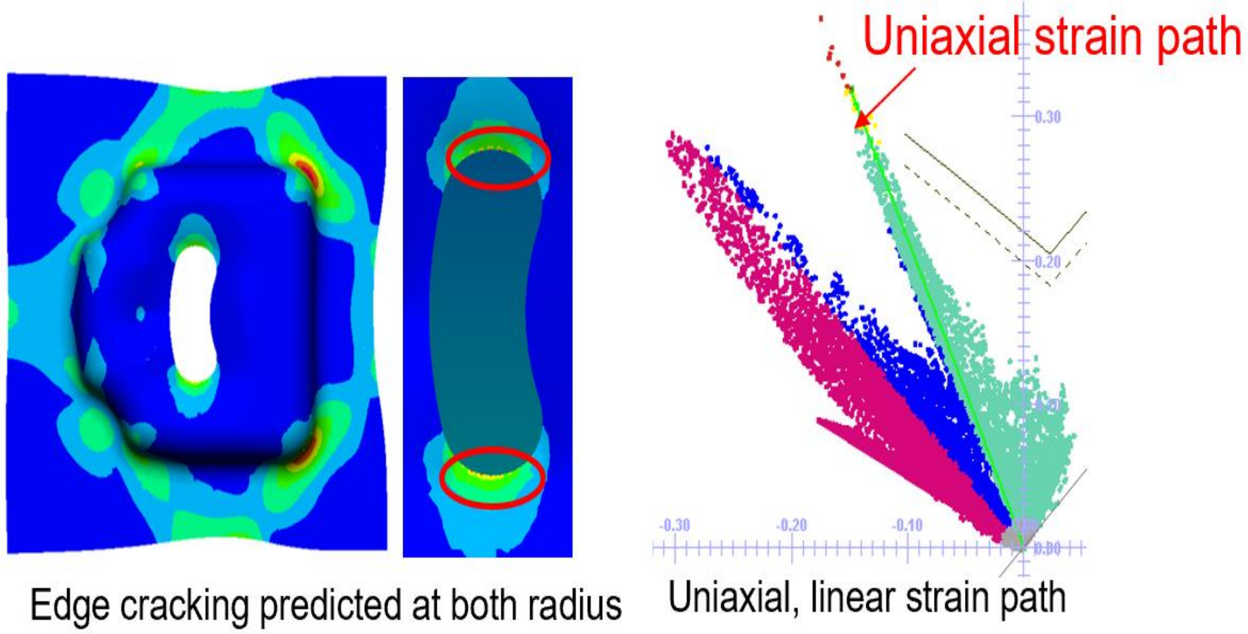
Expected Benefits:

- Measuring failure strain representing the local formability on the sheared edge
- Prediction of edge cracking in finite element (FE) simulation of stamping

DEVELOPING A NEW TESTING METHOD

1. *The Peanut-shaped Hole Punching Test*
2. *The Peanut-shaped Hole Expansion Test (PS-HET)*
3. *Finite Element Analysis*

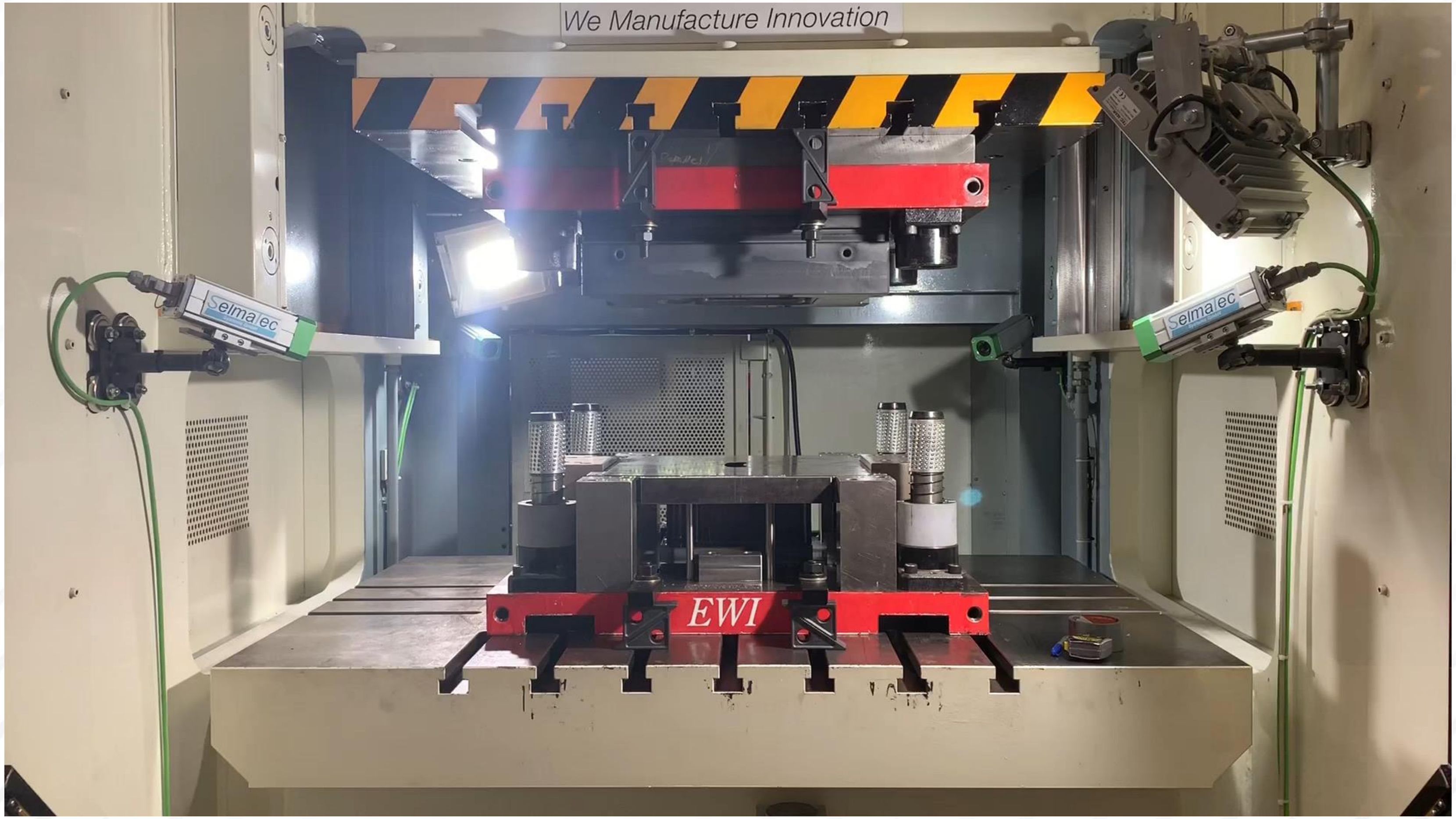
Peanut-shaped punches (left) and punching test tooling (right)



Peanut-shaped hole expansion test simulation result and FEM-predicted strain path

PUNCHING TEST VIDEO

STAMPING TEST VIDEO

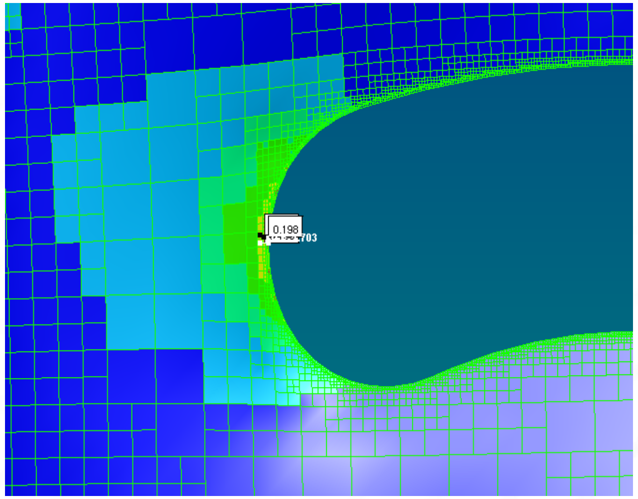


STAMPING TEST

- A 300-ton AIDA servo press was used for experiments.
- 16 Stroke per minute (SPM) corresponding to the maximum speed of 144mm/sec was used for experiments.
- Measured the load-displacement curve during each test
- ARGUS tool was used to measure the strains on the tested samples.

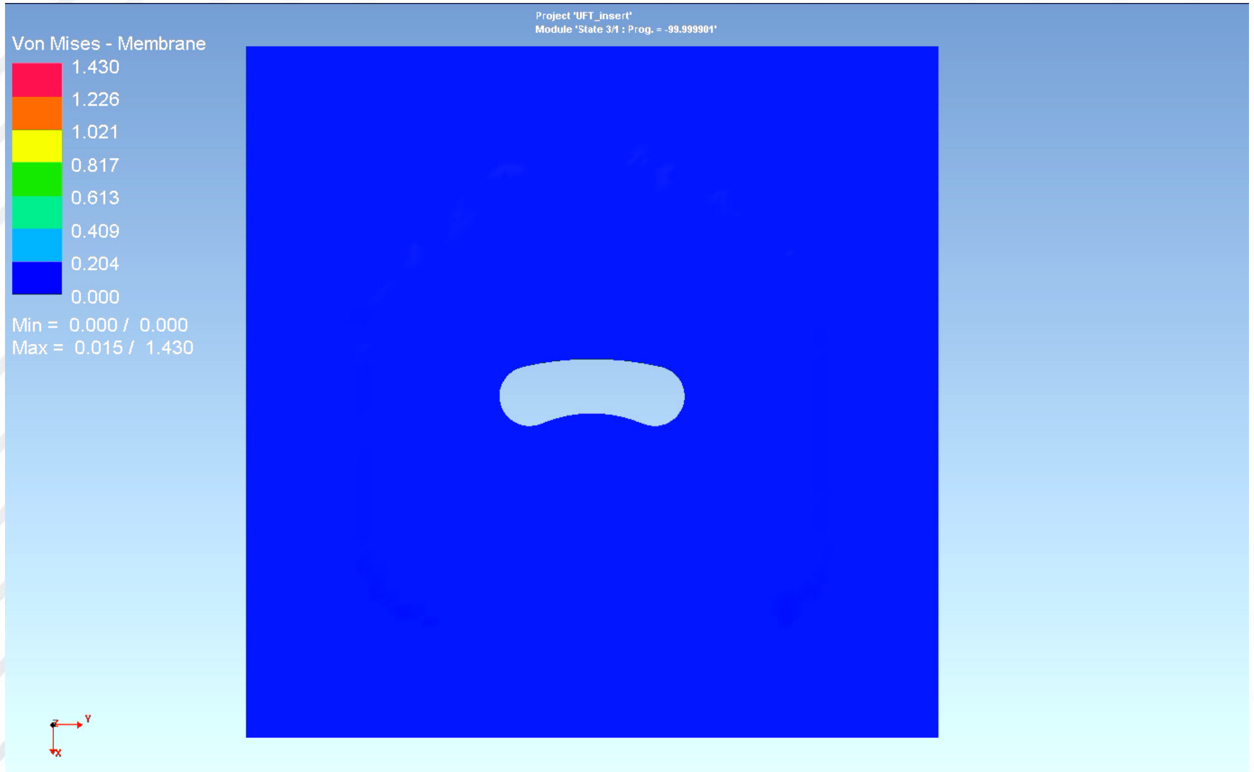
COMPARISON OF EXPERIMENTS AND FEM

- Experiment showed the equivalent strain of 0.20 at the cracking.
- The simulation showed the corresponding equivalent strain of 0.195 at 2 mm from the edge of crack location.

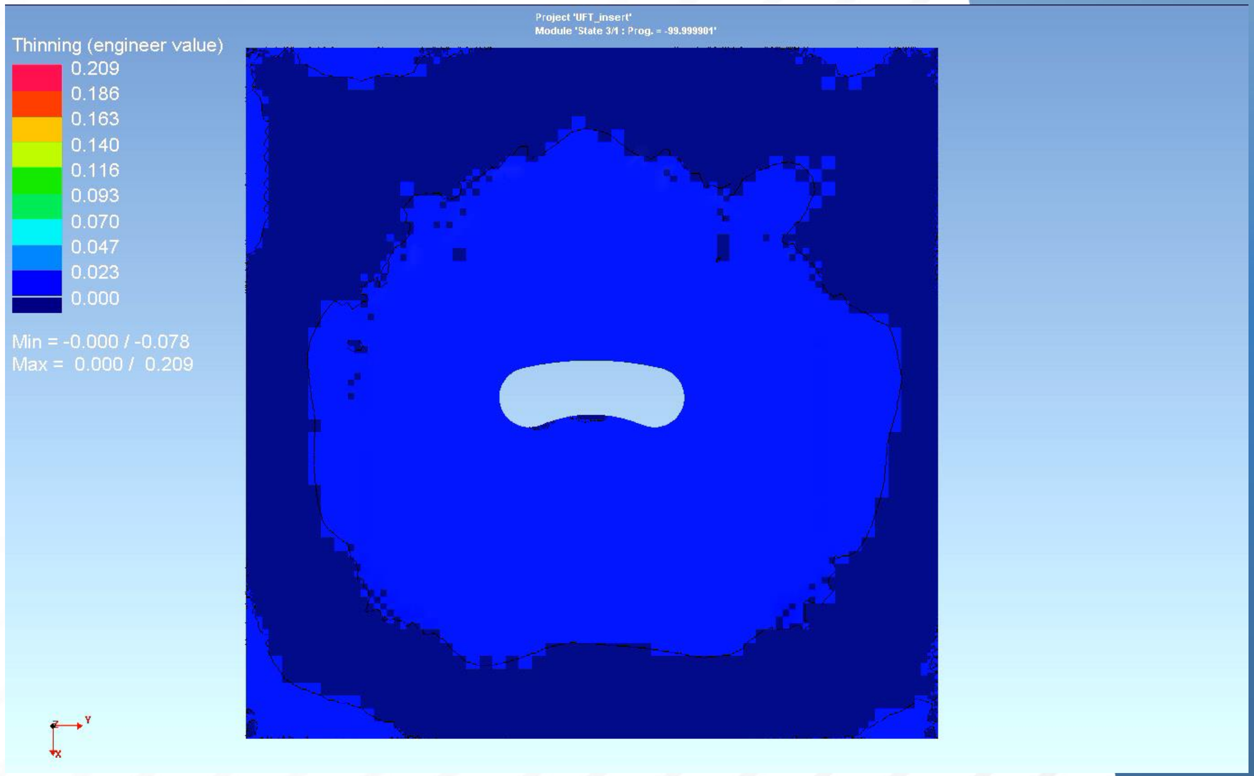


GEN3-980 sample punched with 12% clearance

FE SIMULATION RESULTS – STRESS AND THINNING



von-Mises stress contour for 980GEN3 (1.2 mm)



Thinning contour for 980GEN3 (1.2 mm)

LOAD-STROKE CURVE

- Both experiment and FEM showed good correlation for the load-displacement.
- The first load drop corresponds to the edge cracks initiated at the peanut-shape hole.

MATERIAL TESTED

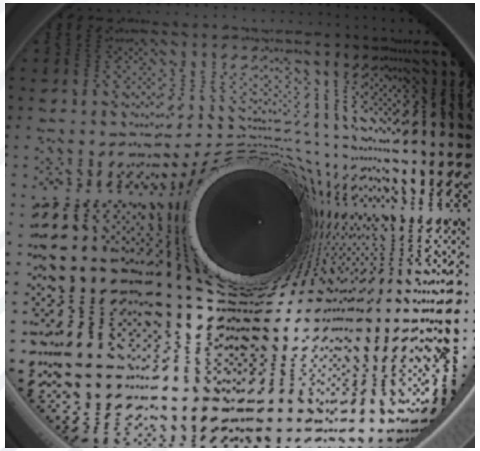
Six different steel suppliers provided the same DP780 materials.

1. Material A: DP780 (t_0=1.5 mm)
2. Material B: DP780 (t_0=1.4 mm)
3. Material C: DP780 (t_0=1.5 mm)
4. Material D: DP780 (t_0=1.5 mm)
5. Material E: DP780 (t_0=1.5 mm)
6. Material F: DP780 (t_0=1.5 mm)

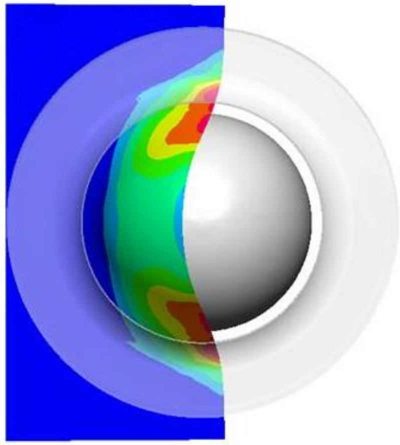
- Three different edge conditions were used:
    - **13% Clearance:** Sheared edge at 13% clearance of the sheet thickness
    - **20% Clearance:** Sheared edge at 20% clearance of the sheet thickness
    - **Machined**: Machined edge

APPROACH

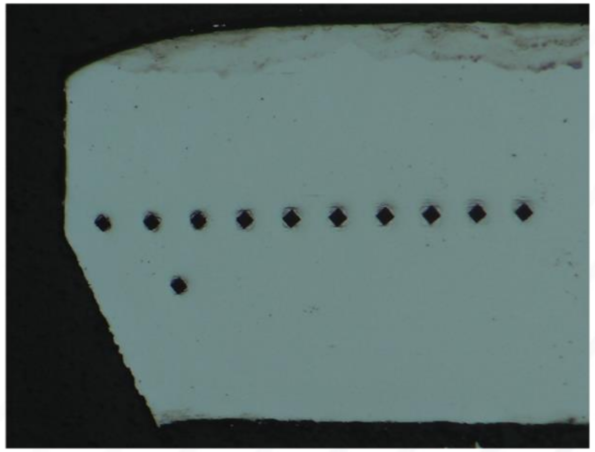
1. *Hole Expansion Testing* → Hole Expansion Ratio (HER)
2. *Half-specimen Dome Testing (HSDT)* → DIC*-measured strains
3. *Microhardness and microstructure analyses* → Hardness (work-hardening)
4. *Stamping Test* → Optically-measured surface strain and failure stroke



Hole Expansion Test



Half-specimen Dome Test



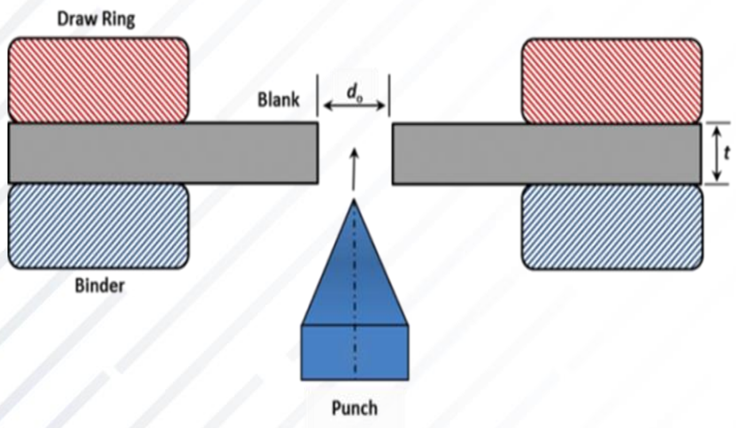
Micro-hardness test

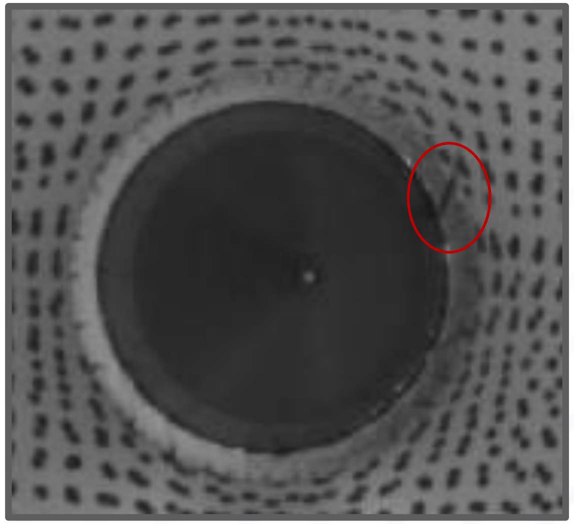
Stamping test

*DIC = digital image correlation

HOLE EXPANSION TEST
ISO-16630 STANDARD

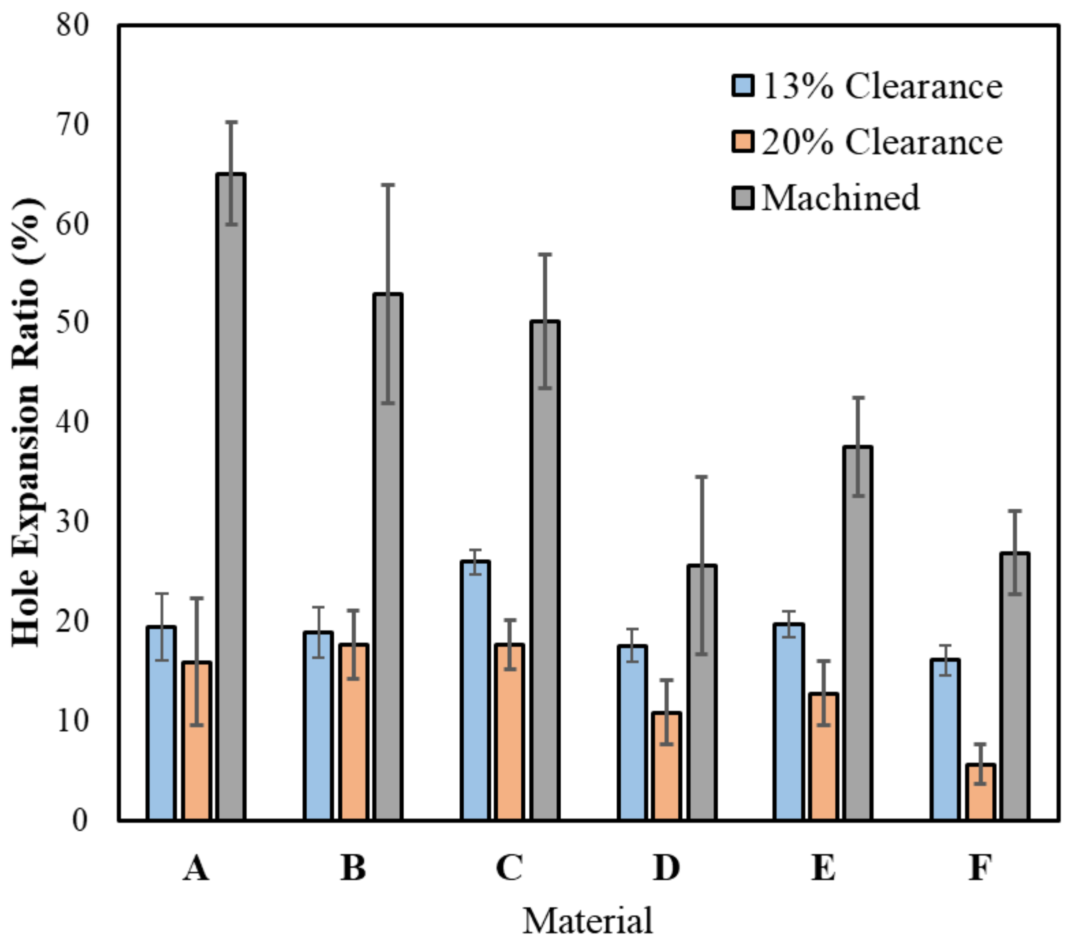
- Hole expansion test is a method to characterize the stretch-flangeability of a material using the hole expansion ratio (HER).
- A conical punch with 60 degrees included angle is used to expand a 10-mm diameter machined hole until a through-thickness crack appears. A sample is fully clamped in the die.





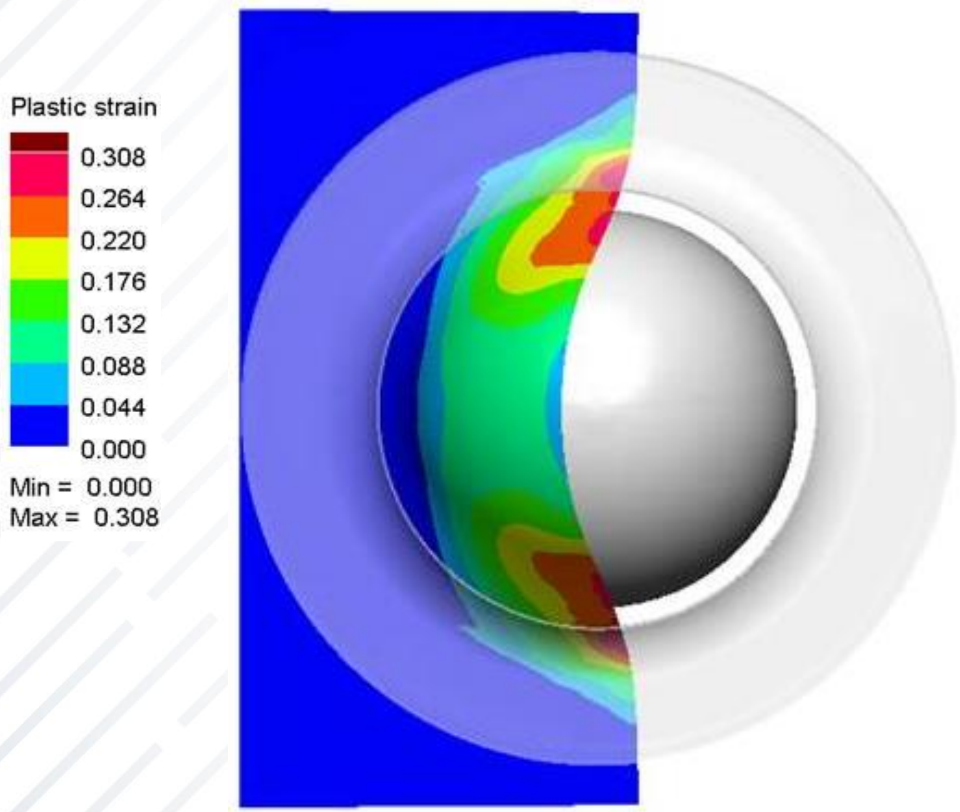
The Erichsen testing machine at EWI

HOLE EXPANSION TEST RESULTS



- The machined edge showed a larger HER due to minimal work-hardening.
- The edge formability for the edges sheared at 13% clearance is similar for all the materials, except Material C that shows a slightly higher edge formability compared to the other materials.
- Materials A and B showed no significant difference in edge formability observed between the edges sheared at 13% and 20%.
- Material F gave the maximum difference between the HER for the two sheared edge conditions (13% and 20%).
- Materials A, B and C showed slightly higher edge formability than others.

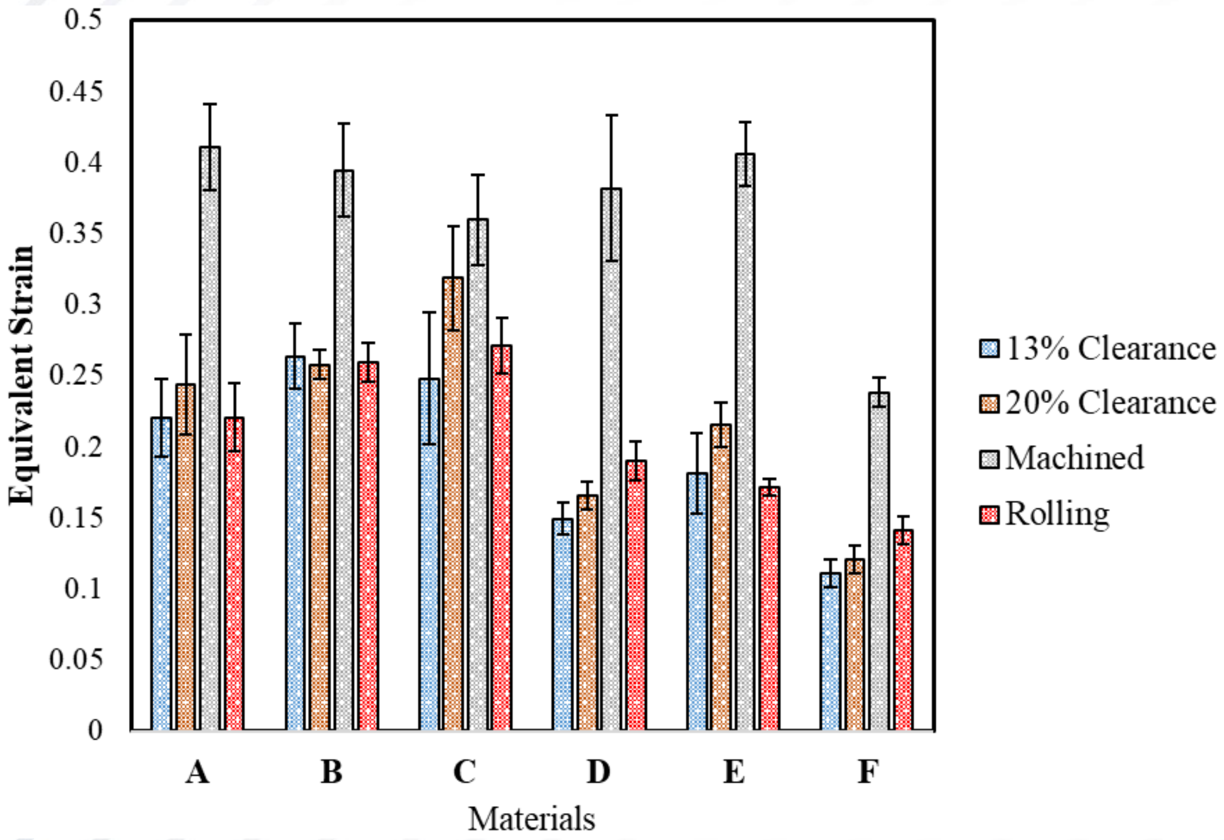
HALF-SPECIMEN DOME TEST
EDGE FORMABILITY TEST



An FE model of the HSDT

- HSDT can be used to evaluate sheared edge stretch-ability.
- The major advantage of HSDT is the ability to differentiate between rolling and transverse directions.
- DIC was used to record deformation and provide strain measurements.
- EWI conducted HSDT on the four different edge conditions along the rolling direction:
  - **13% Clearance:** 13% clearance
  - **20% Clearance:** 20% clearance
  - **Machined:** Machined
  - **Rolling:** 13% clearance

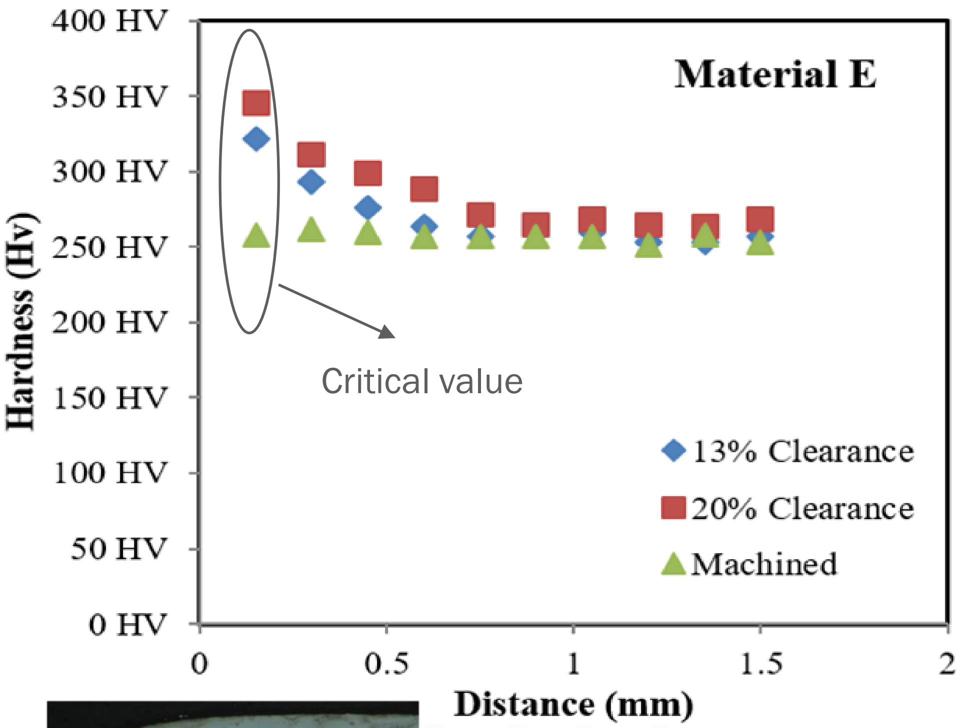
HALF-SPECIMEN DOME TEST RESULTS

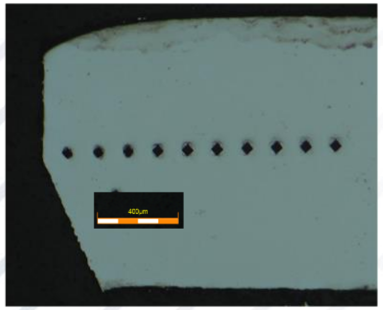


Note: All the tested samples had the edge parallel to transverse direction.

- The machined edge showed a larger edge formability due to minimal work-hardening.
- Material F has the lowest edge formability.
- Most materials did not show significant difference in edge formability between the edges sheared at 13% and 20%.
- Materials A, B, and C showed a higher sheared edge formability compared to the other materials.
- No significant difference was observed between the edge sheared along the rolling and transverse directions.

HARDNESS MEASUREMENT



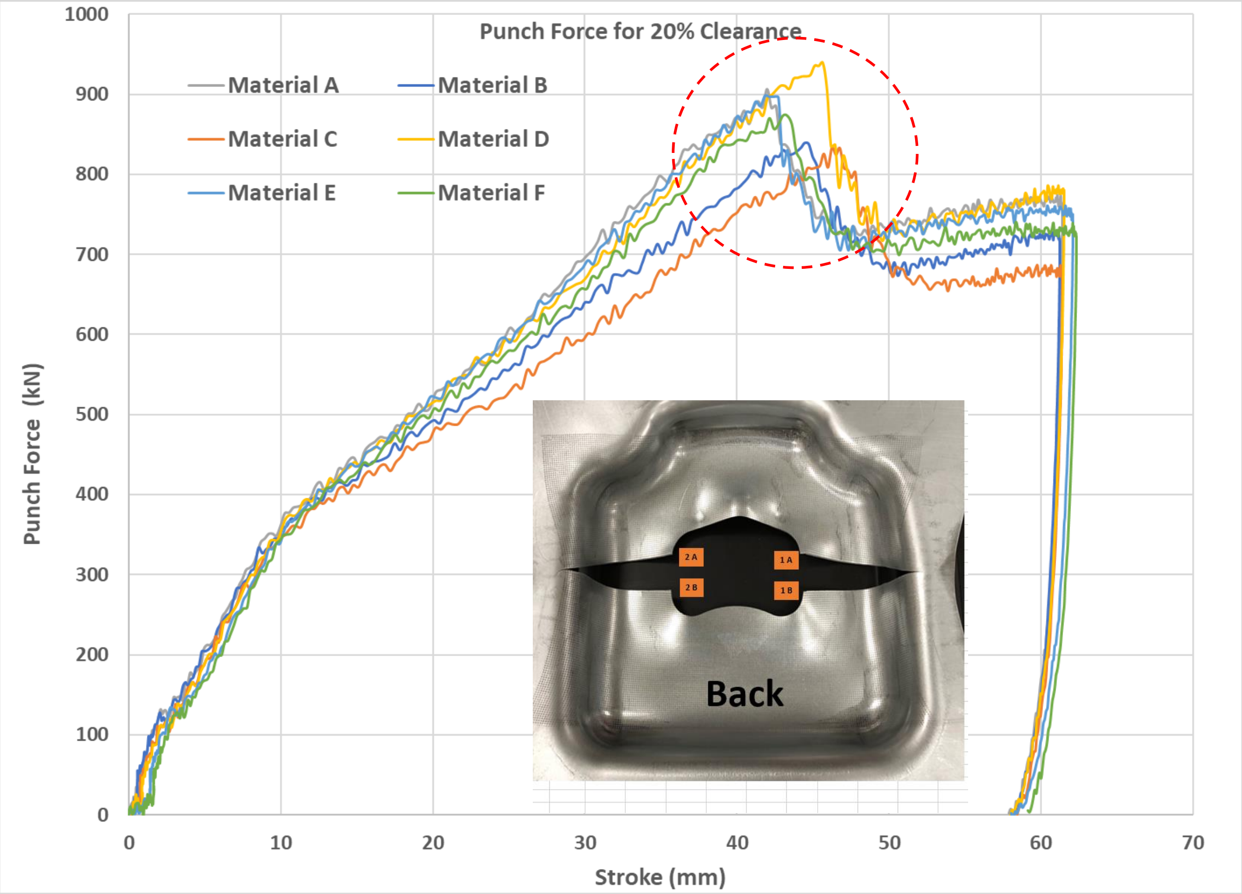


- Hardness measurements were conducted along through-thickness direction.
- The first measurement is the highest and critical to edge formability, $HV_{critical}$
- The work-hardening matrix is defined for both the sheared edge conditions as

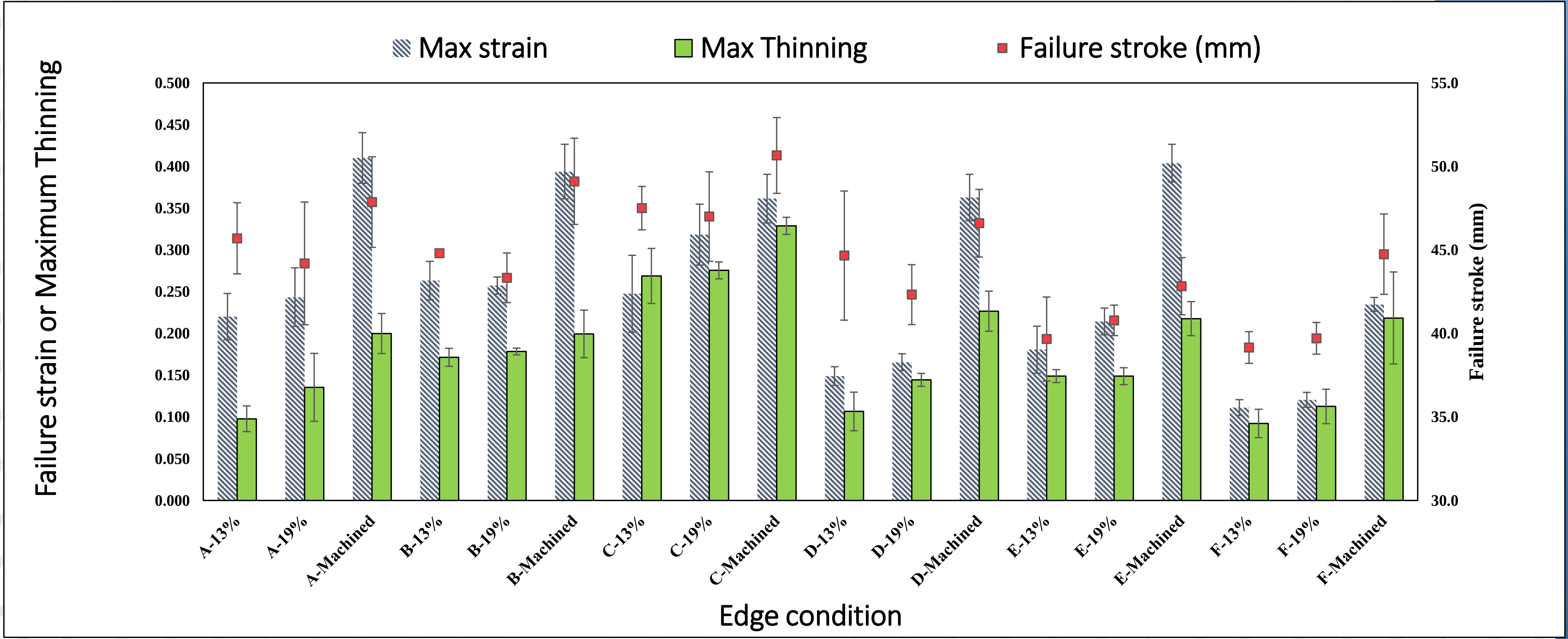
$$Work - hardening = \left[\frac{HV_{critical} - HV_{base}}{HV_{base}}\right]$$

STAMPING TEST

- Measured the load-displacement curve during each test
- A drop in press load correlates to the onset of edge cracking.
- The die stroke value at the load drop location was compared for the six different DP780 materials.
- A higher stroke value indicates better edge formability.



COMPARISON OF HSDT RESULTS AND STAMPING TEST RESULTS



CONCLUSIONS

- A new testing method is effective to evaluate edge cracking.
- The stamping test results confirmed the Hole Expansion Test result.
- A higher work-hardening is observed on the sheared edges compared to the machined edges.
- Materials A, B and C showed less sensitive to the variation in sheared edge condition compared to other D, E, and F materials.
- Material C showed the best performance in terms of the minimum damage and work hardening during shearing at 13% and 19% clearances.

FOR MORE INFORMATION

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