GREAT DESIGNS IN STEEL

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GREAT DESIGNS IN STEEL

AHSS STRETCH-BEND FRACTURE LIMIT STRAINS ON PART RADII

AUTO/STEEL PARTNERSHIP

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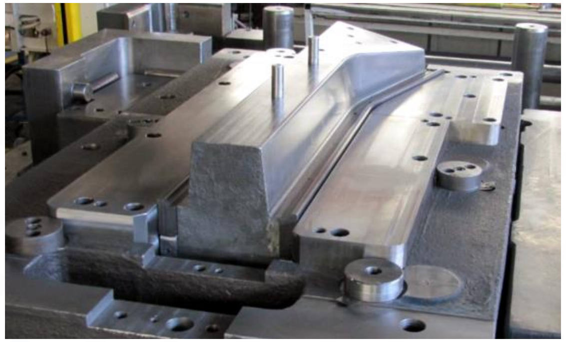
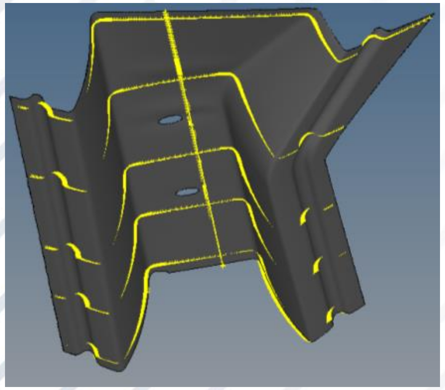
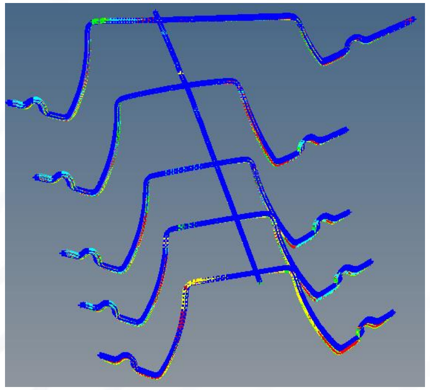
AHSS SPRINGBACK & TWIST CONTROL VS FORMABILITY

Springback & twist control







The springback and twist increase with the steel strength. To combat the problems, the punch and die radii were reduced to control the angular springback and sidewall curl. Also, the sharp drawbeads/stake beads were used to stretch the part for shape control. Thus, the AHSS stretch bendability has emerged as an issue for the use of these correction measures

TABLE 1: STAKE BEAD INSERT HEIGHTS (mm)

Insert Zone	A	B	C	D	E	F
CASE-1	10	10	10	10	10	12
CASE-2	10	11	12	11	11	10

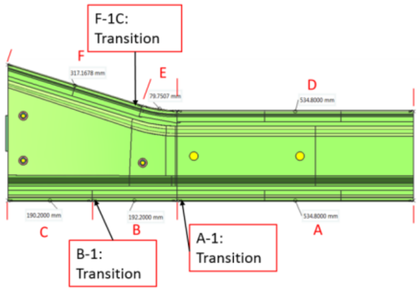
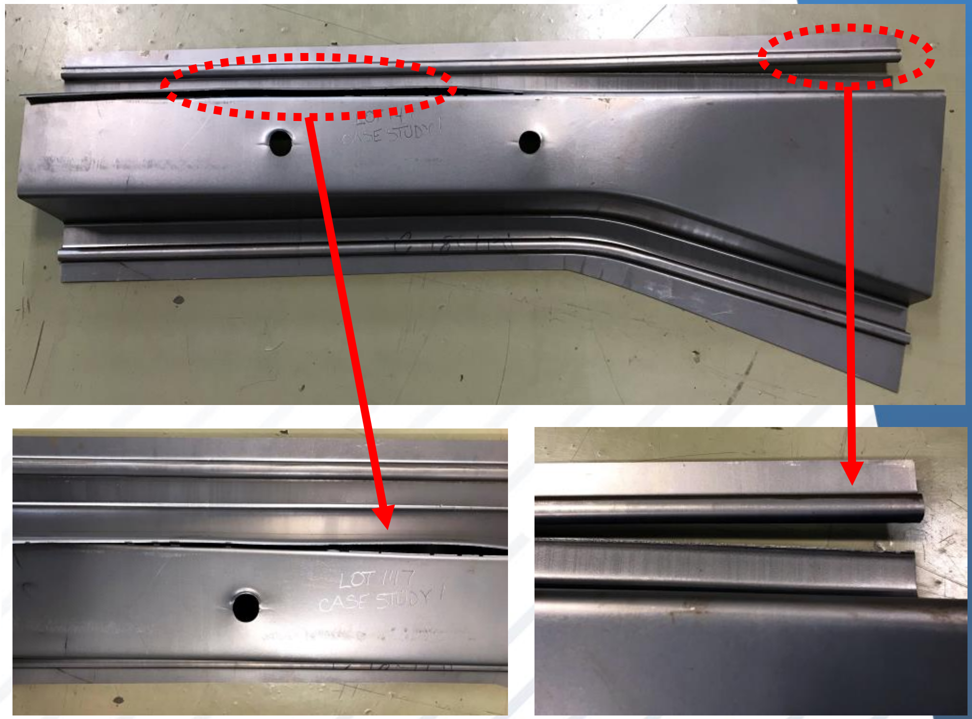


Figure 1: Figure 1. Stake bead layout

AHSS stretch bendability



FAILURES AROUND THE PART RADII

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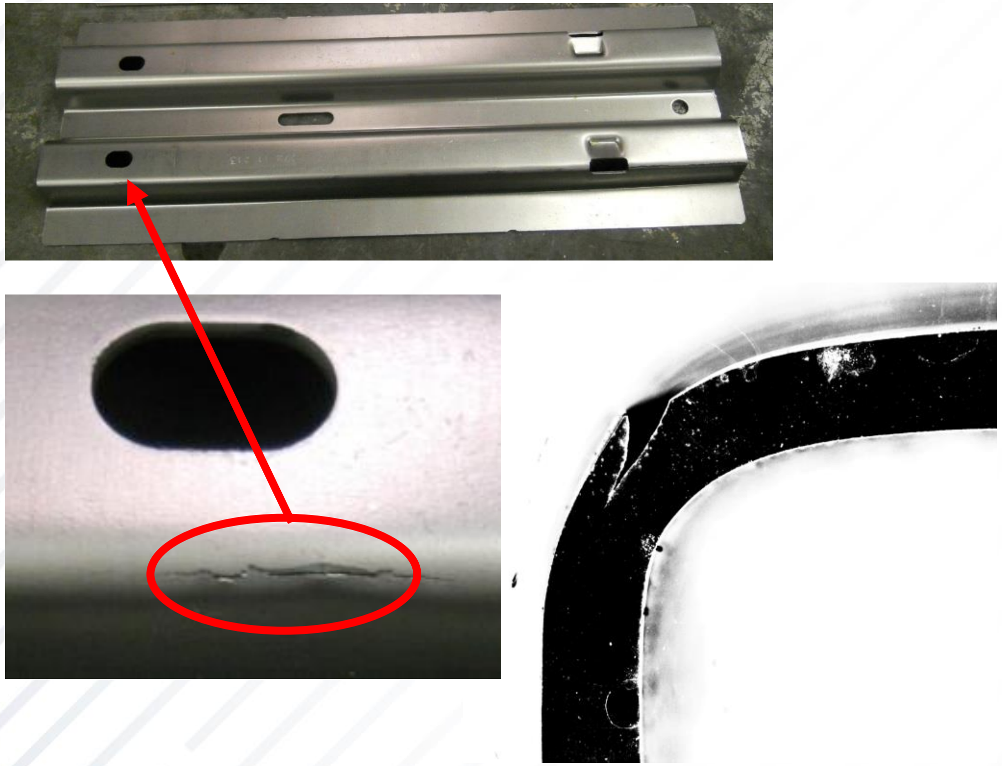
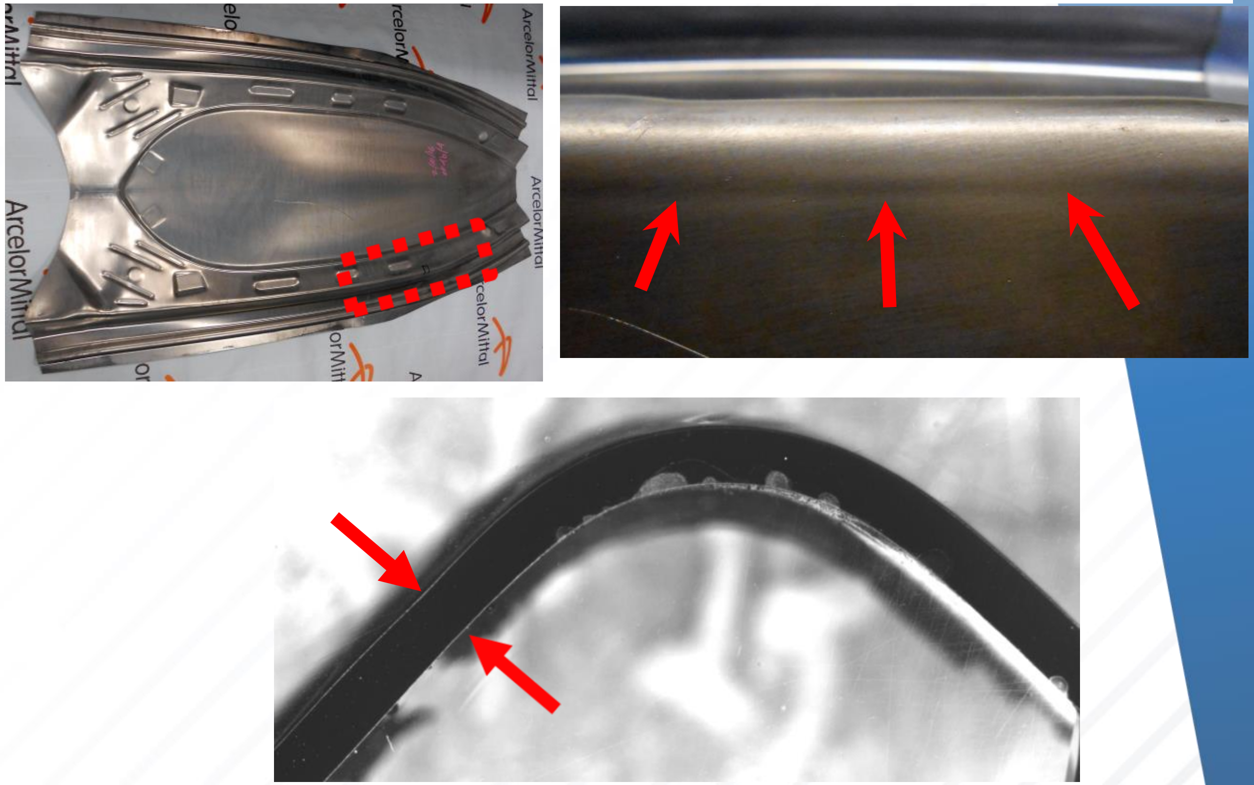
Fracture on Part Radii



Necking at the Tangent Point of Part Radii



Two failures commonly found around the part radii:

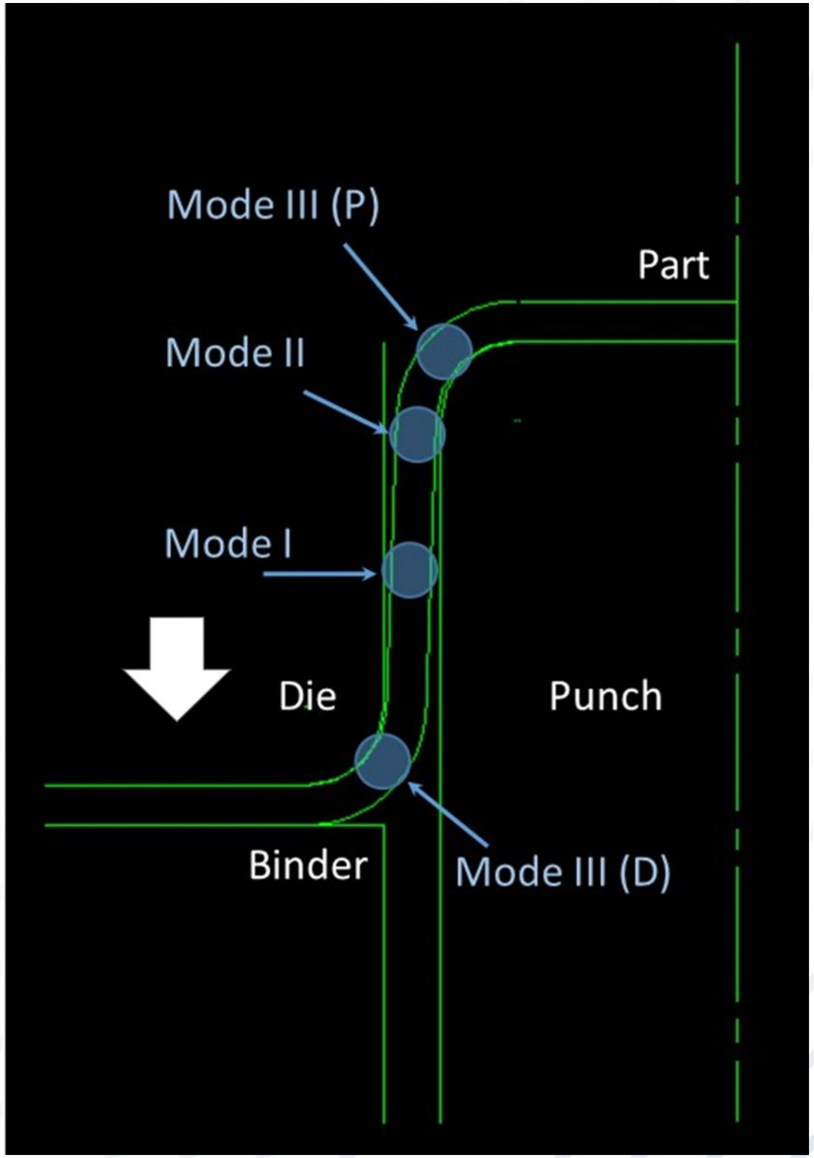
- ❖ Fractures on part radii – No necking preceded the fractures
- ❖ Necking at the tangent point of part radii – Controlled by the steel terminal n value (Huang, 2008)

FAILURES IN A STAMPED PART

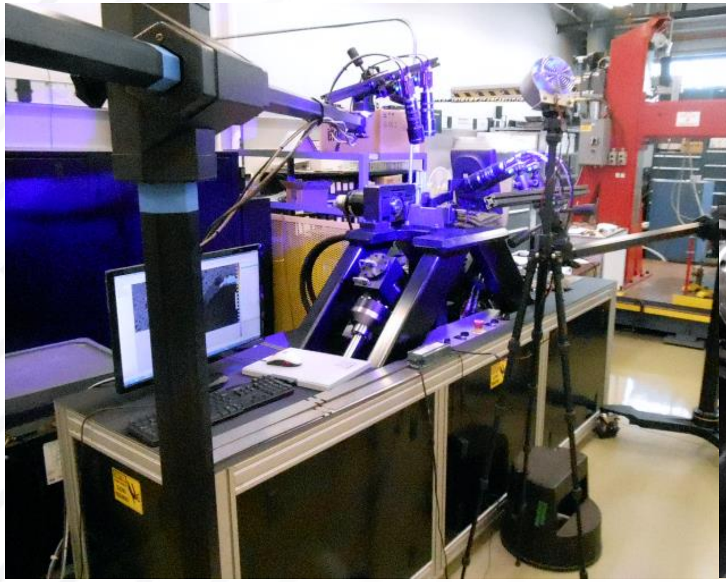
Three failures modes:

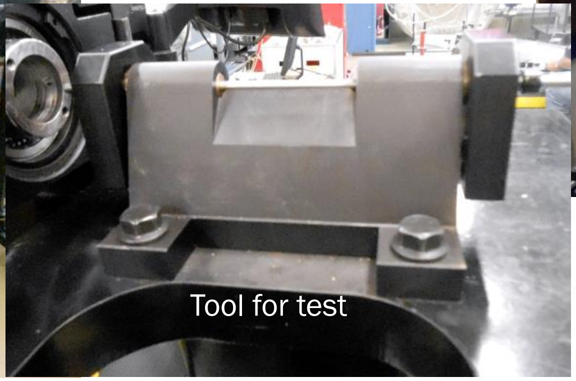
- ❖ Necking of part wall
  - Failure criterion: FLD
  - Occurrence: on part walls
  - Root cause: plastic instability due to excessive in-plane stretch
- ❖ Necking of tangent point of part radii
  - Failure criterion: terminal n value
  - Occurrence: on the tangent points of part radii
  - Root cause: plastic instability due to through thickness shearing
- ❖ Fracture on part radii
  - Failure criterion: to be determined
  - Occurrence: on part radii
  - Root cause: to be investigated

Schematic of Failures

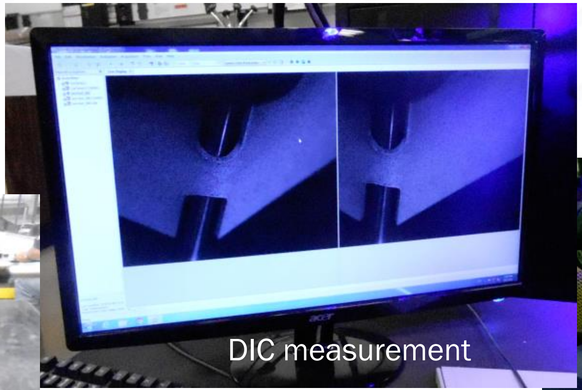


90° STRETCH BEND TEST

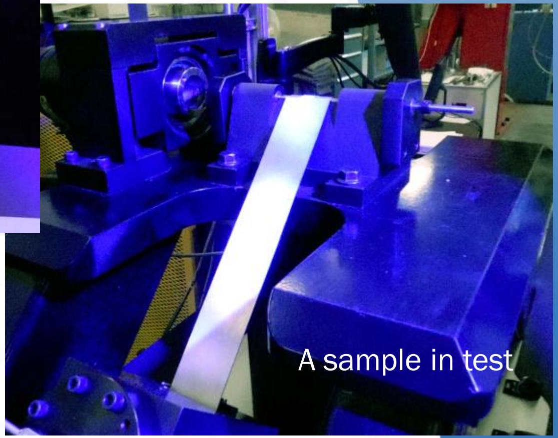




Tool for test



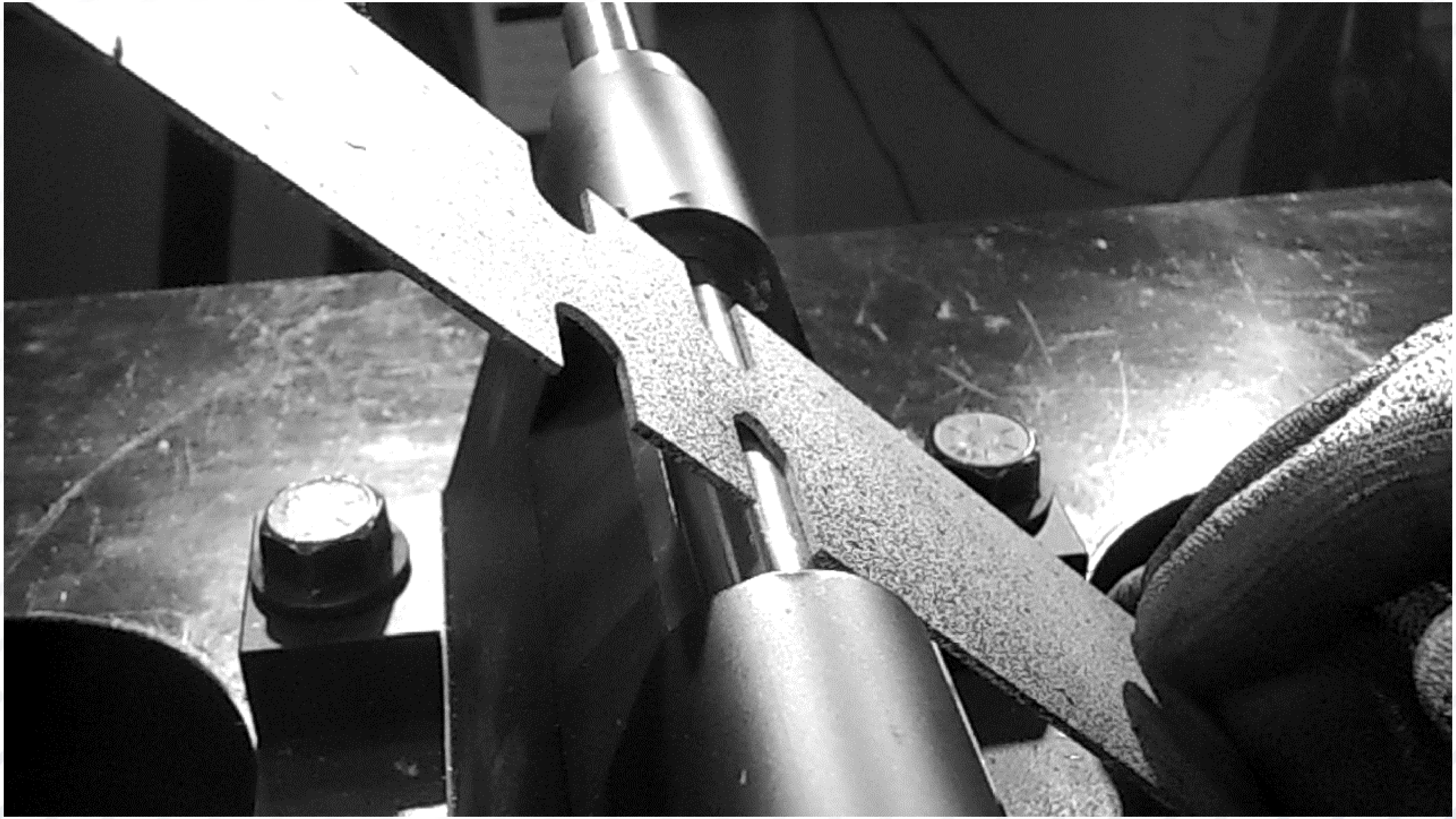
DIC measurement



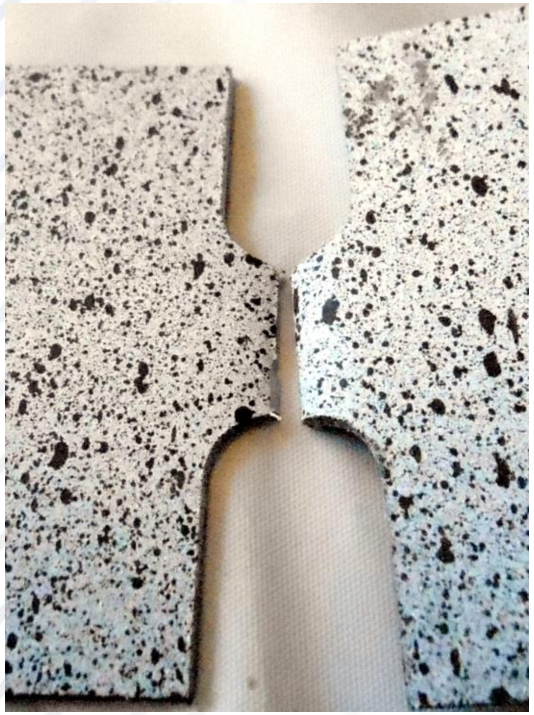
A sample in test

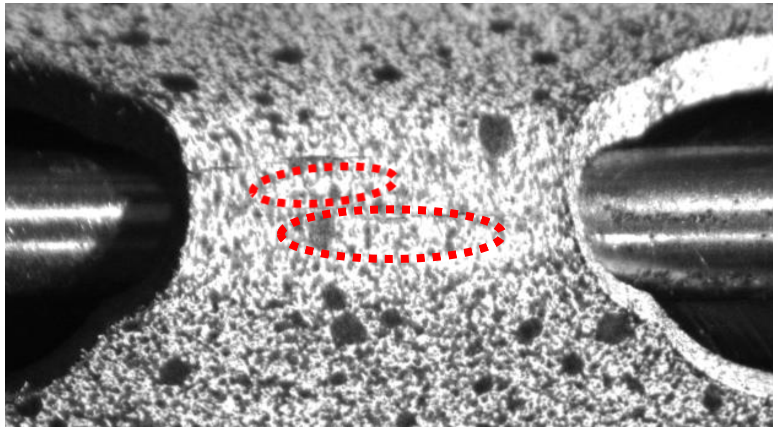
- The 90° stretch bend test was conducted with an Interlaken 90° stretch bend tester and a DIC strain measurement system
- The test measures the AHSS stretch bend limit strains with 90° bend and under the plane strain condition
- Test tools radii used are ranged from 1.0, 2.0, 3.0, 4.0, 5.0, 6.0, 7.0, 8.0, 9.0, 10.0, 12.0 to 14.0mm
- Four AHSS materials tested are DP590, DP780, DP980 and DP1180. The gauge varied from 1.20mm to 1.50mm

90^0 STRETCH BEND TEST

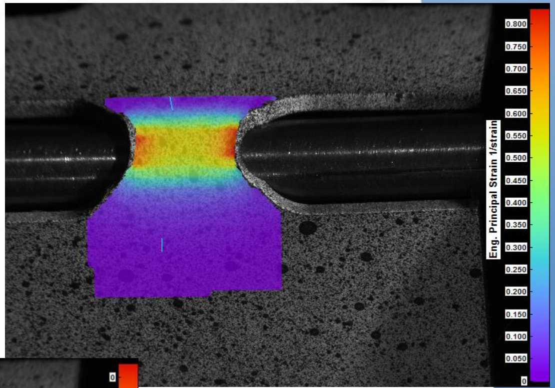


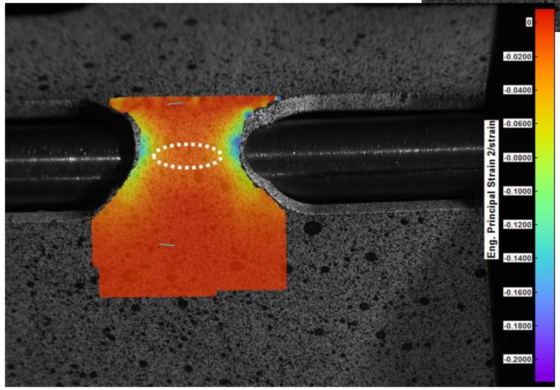
FRACTURES OF AHSS ON PART RADII





Major Strains





Minor Strains

- The fractured sample shown above is the DP980 material tested with a tool of R=2.0mm
- Surface fractures were captured by the cameras before the sample breakage. No necking or edge fracture detected
- The strain measurements demonstrate that the surface fractures occurred under a plane strain condition

FRACTURE LIMIT STRAIN MEASUREMENTS

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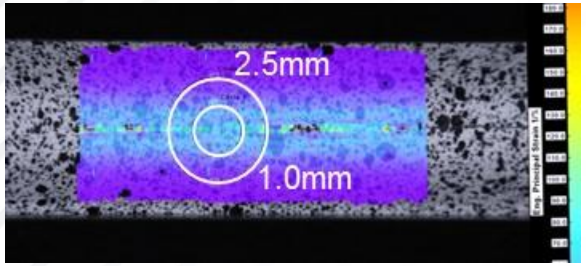
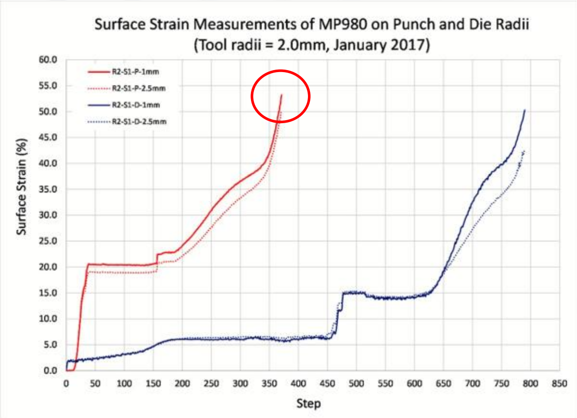
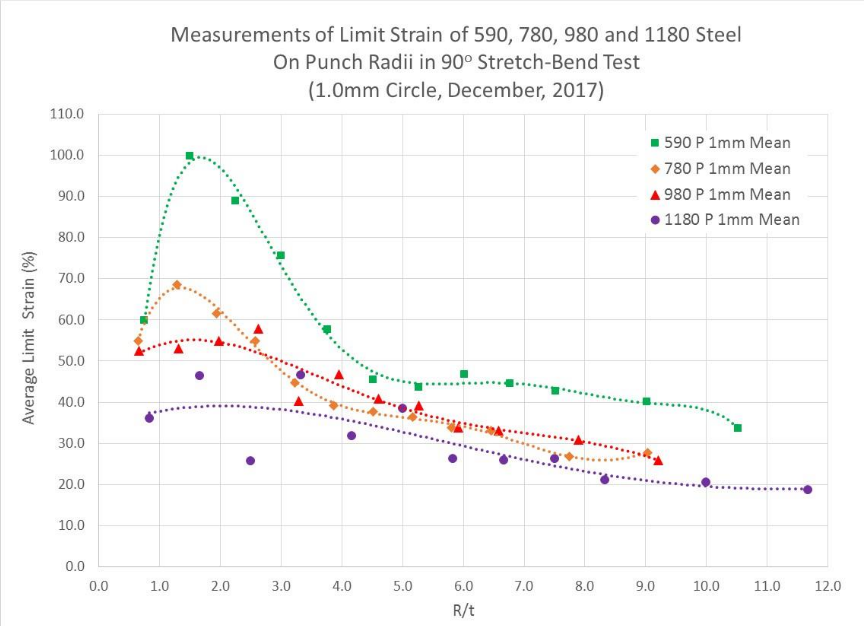


Major strains were calculated with the circles of 1.0 and 2.5mm diameters to get the surface strains

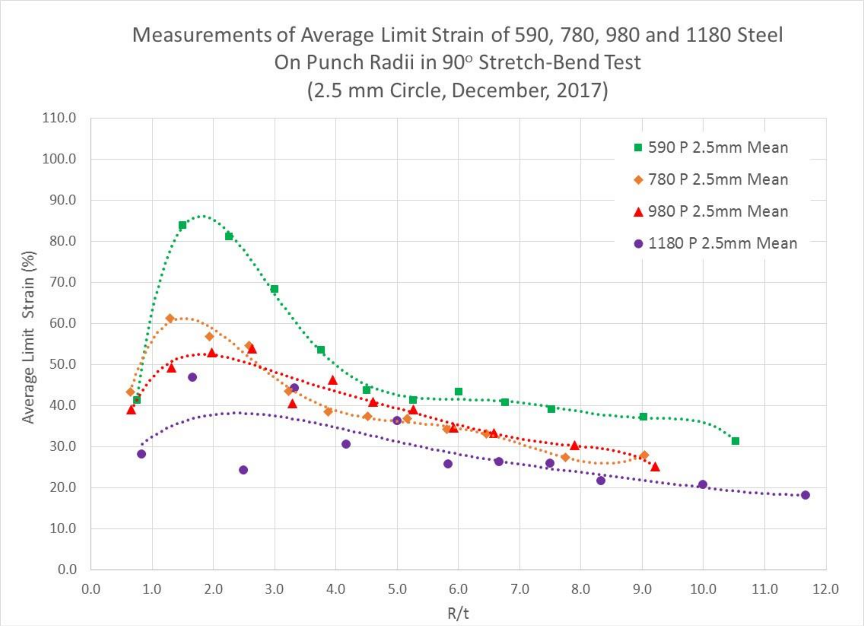


The fracture limit strain is calculated from the strain measurement prior to the sample breakage

Limit Strains (1.0mm)



Limit Strains (2.5mm)



- Three samples were tested for each tool radius. The fracture limit strain measurement results are averaged and plotted in the above figures
- The limit strains were calculated with both 1.0mm and 2.5mm circles
- In the above figures, the trends of the results for 1.0mm and 2.5mm circles are the same though the values of 2.5mm circles are generally lower than 1.0mm circles due to the bigger averaging effects

SUMMARY OF AHSS STRETCH BEND RESULTS

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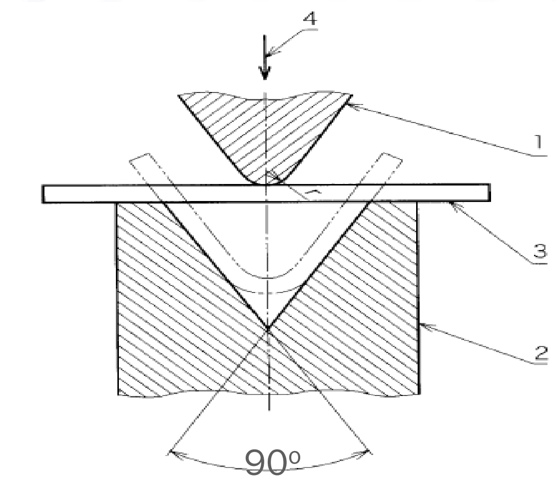
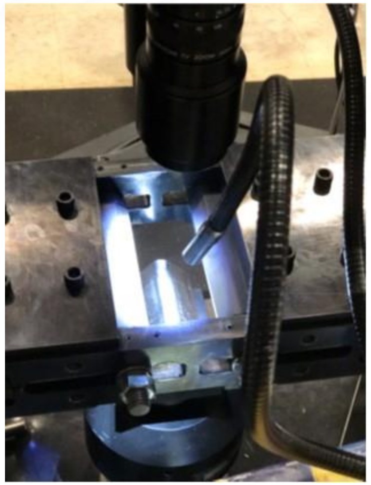
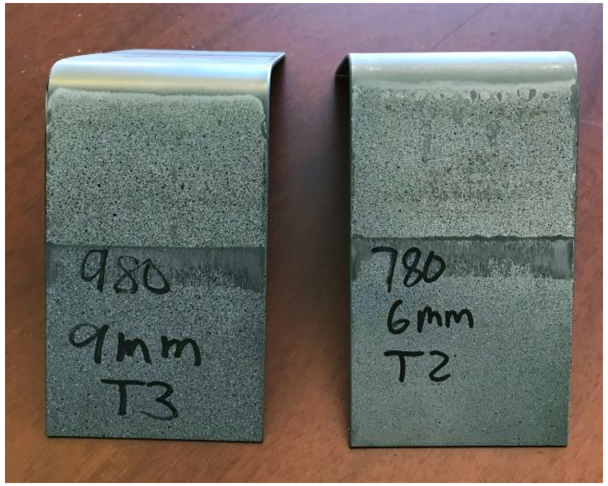
- The test results can be used as a design guideline and failure prevention criterion in the product and process development. It can also be used in the stamping plant to prevent the AHSS formability issues on part radii
- The test results show that the limit strains of AHSS are similar for the part radii formed with punch and die. The pre-strains did not show any significant effects on the fracture limit strains
- It is recommended to use 1.0mm square grids for the AHSS formed with tools of R/t ratios less than 5.0. The 2.5mm grids can be used for larger tool radii with R/t ratio > 5.0.

90º BEND TEST







- 90º bend test was developed with a test fixture designed and fabricated by the ArcelorMittal Global RD – East Chicago and a DIC strain measurement system
- The test determines AHSS surface strains in a 90º plane strain bending
- The tools used in the 90º bend test have the radii similar to those used in the stretch bend test (from 1.0 to 14.0mm). The bending fracture may occur depending on the material properties and tool radii
- The same group of materials (DP590, DP780, 980 and DP1180) used in the stretch bend test were tested here

90^0 BEND TEST RESULTS

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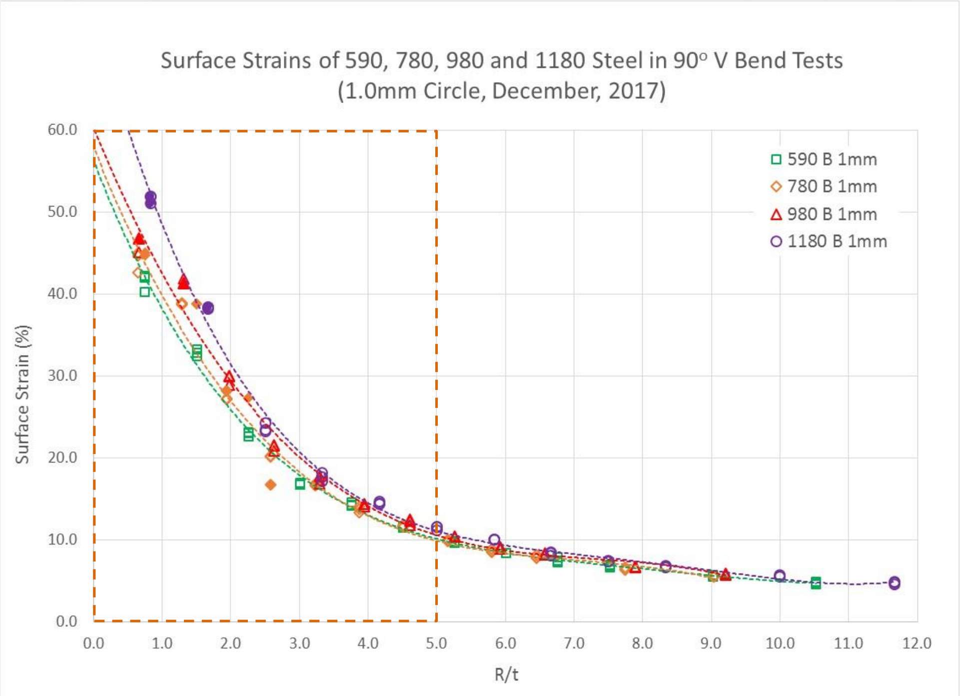
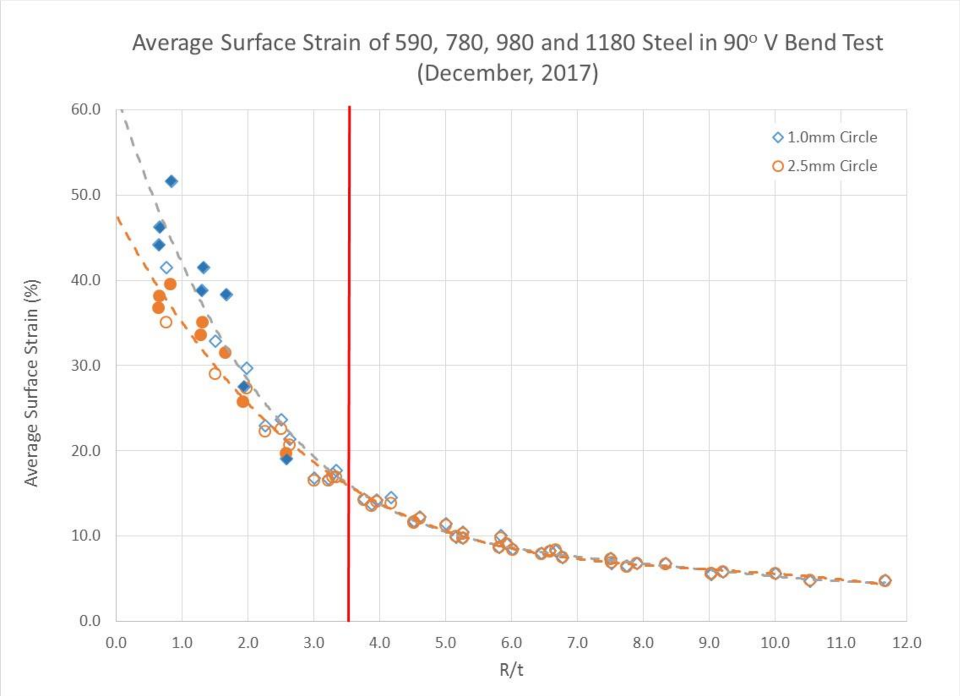
Surface Bending Strains Measurements





- The results in above figures show that the differences in the surface strains of AHSS materials are insignificant for R/t > 5.0 (small curvature bending according to R. Hill), The bending strain is controlled by the tool radii (tool geometry)
- For R/t < 5.0 or large curvature bending, the differences in the AHSS surface bending strains are increased with the R/t ratio. The Higher the steel strength, the larger the surface bending strain. The difference in the surface strains for DP590 and DP1180 can be larger than 10% in engineering strain

STRETCH BEND = BEND + STRETCH

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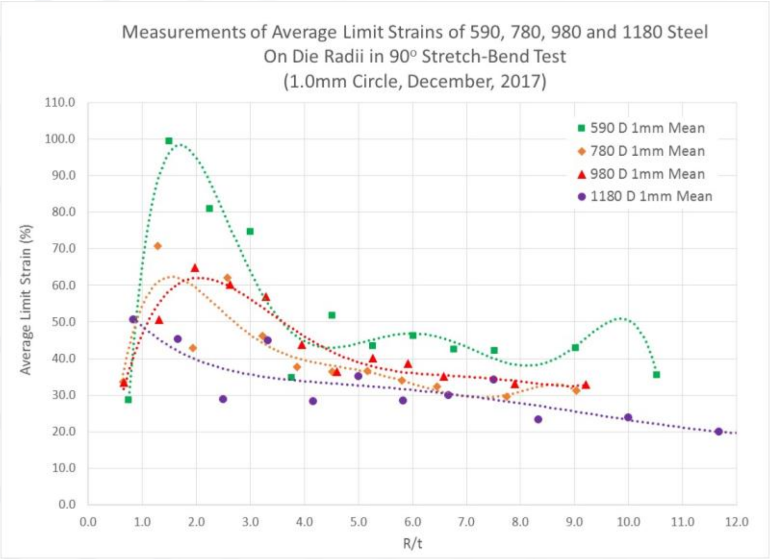
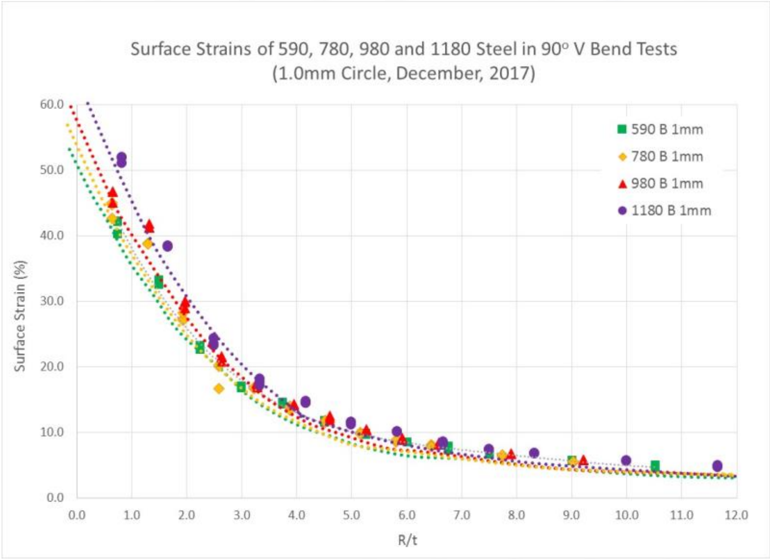
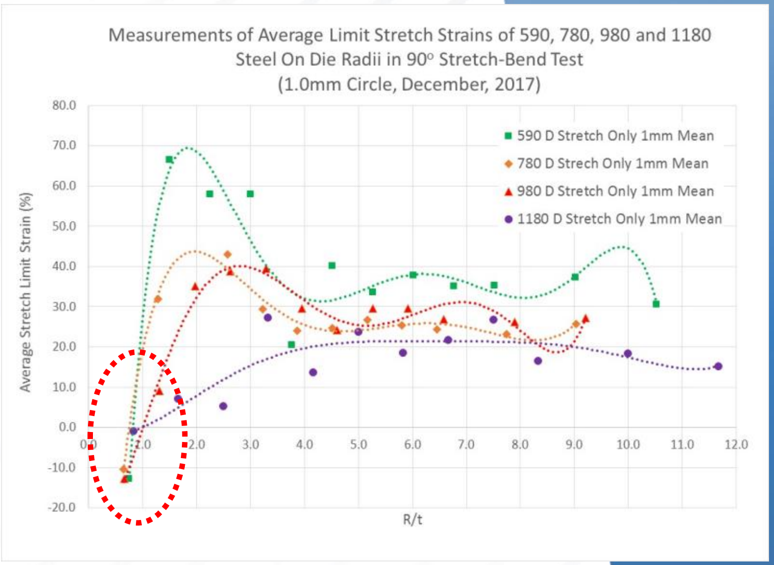
Fracture Limit Strain (ε_{limit}) = **Bending Strain (ε_{bend})** + **Stretch Strain ($\varepsilon_{tensile}$)**





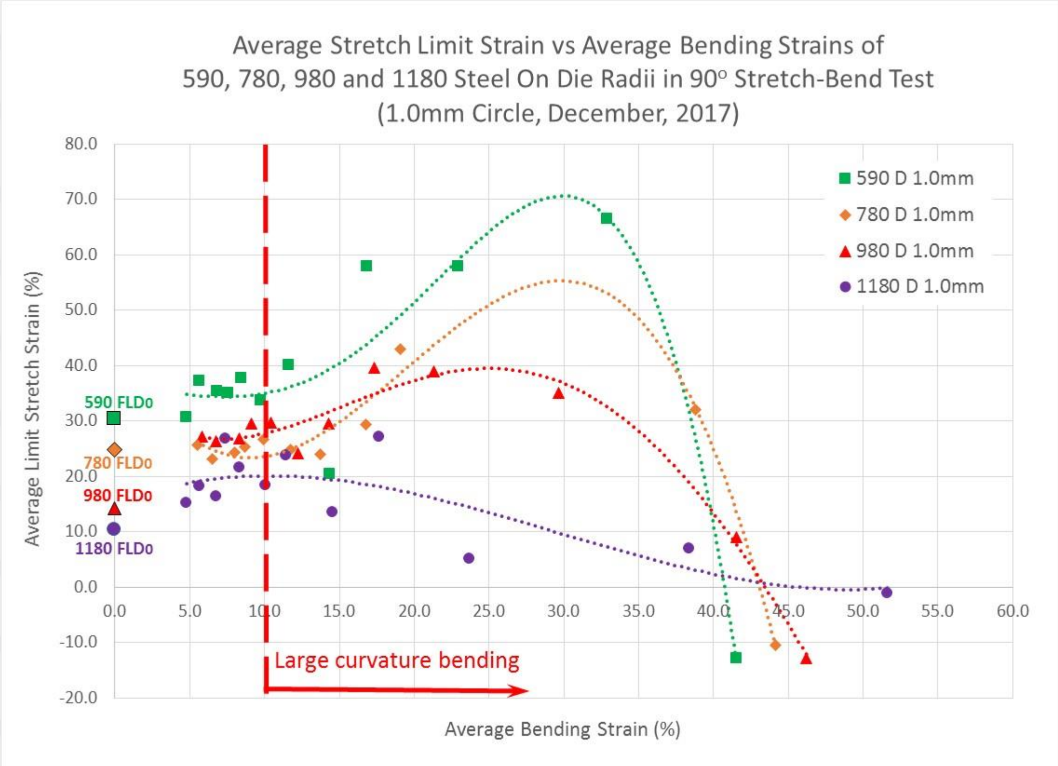


- Fracture limit strains can be assumed as a composition of bending and stretching strains

$$\varepsilon_{limit} = \varepsilon_{bend} + \varepsilon_{stretch}$$

- The decomposition was done with true strains
- A careful examination reveals that the bending strain measurements are sometimes higher than the stretch-bending strain measurements. This is due to the fact that the sample can bent further with some surface fractures. On the other hand, the tension load would normally pull the sample apart after the cracks appeared. Thus, it is not suitable for us to use the AHSS bending limit as an estimate of AHSS stretch bendability

STRETCHING VS BENDING



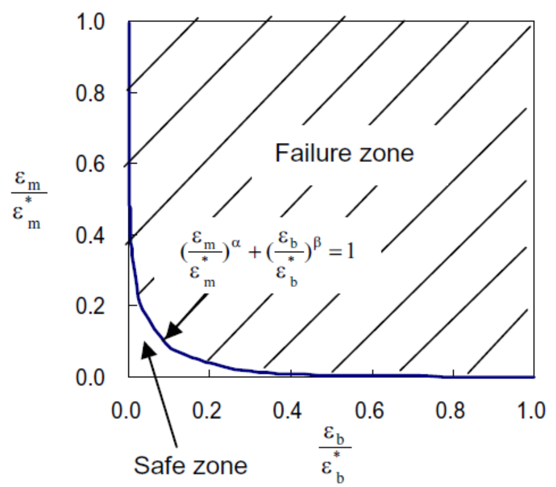
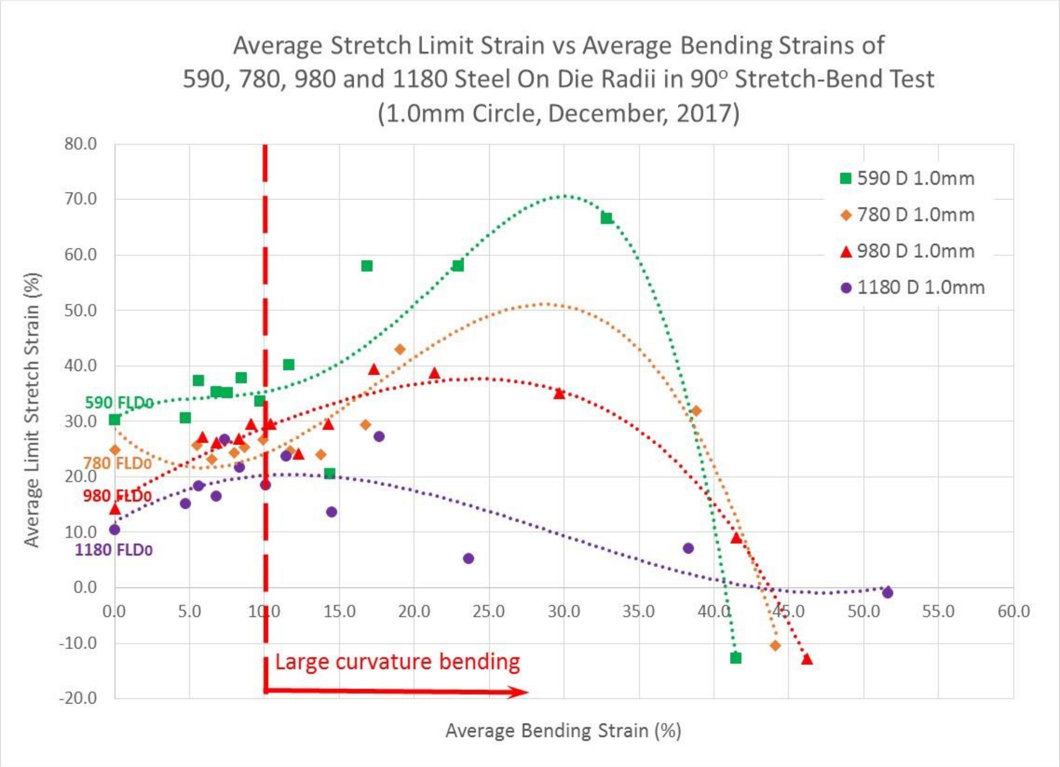


Figure 6. Illustration of stretch-bend failure criterion for 1.19mm, DP600

Previously, some studies suggested that, for stretch-bending, the stretch strain would decrease if the bending strain was increased. Please see the figure above for example (*"A failure criterion for stretch bendability of Advanced High Strength Steels",* J. Wu et al. SAE 2006-01-0349)

- The above figure shows the stretch strains verse bending strains
- It is found that the stretch strains do not decrease monotonically with the increase of bending strains. The stretch strains change dramatically when the bending strains are larger than 10%, which marks a transition of small curvature bending to large curvature bending (bending strains ≥ 10% →R/t ≤ 5.0) . The stretch strains of some materials seem to increase with the bending strains to the apexes and then drop

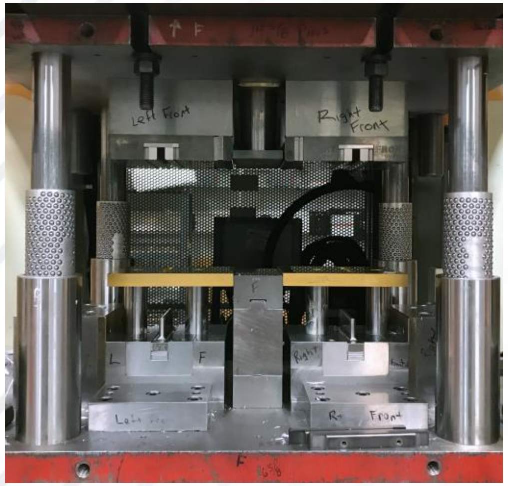
STRETCH BENDABILITY AND FLD_0

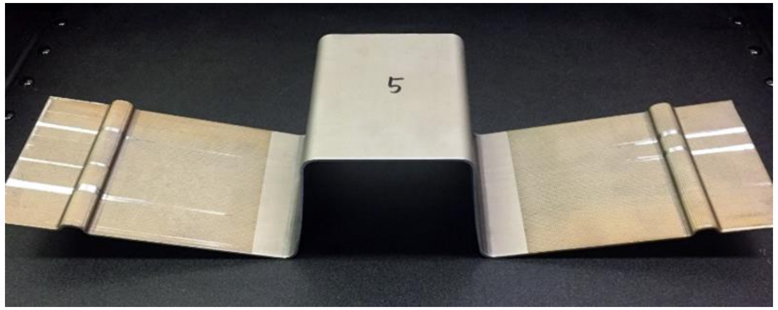


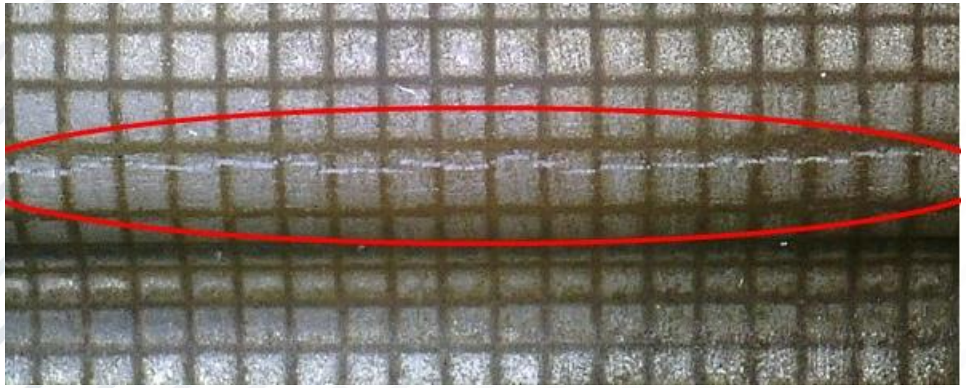
- The limit strains of stretch bending could approach FLD_0s if the bending strains are vanished. In our study, it seems the curves of limit strains of stretch bending fit the FLD_0 reasonably well
- However, it is important to understand how and when the limit strains in stretch bending have been TRANSFORMED from surface fractures to necking / plastic instability because they are two different things in nature and should have some different mechanisms

ONGOING WORK IN THE VERIFICATION

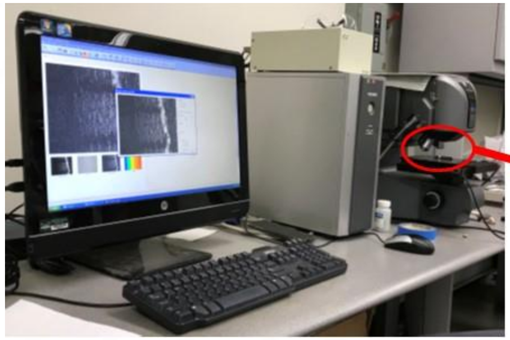
Lab Simulative Forming Test (Channel draw Test)

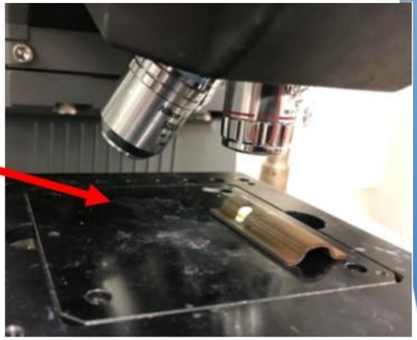


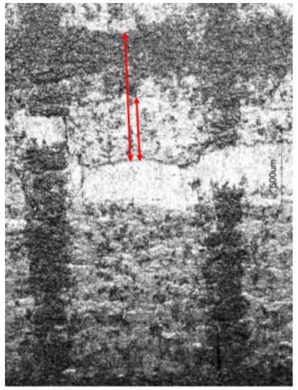


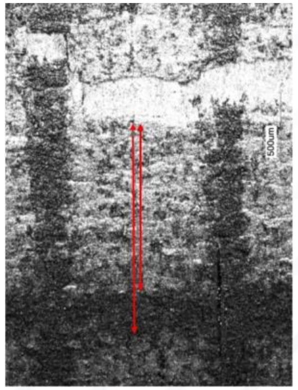


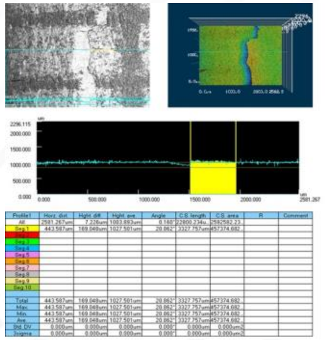
Grid Measurements with 3D Laser Scanning Confocal Microscope

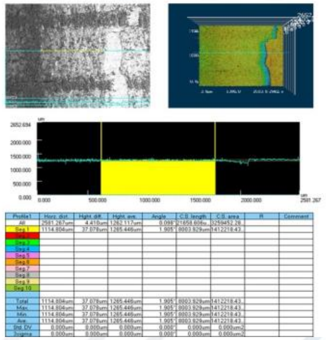












SUMMARY

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- The study indicates that; in the large curvature bending domain, the material work hardening properties play an important role in the AHSS bendability and stretch bendability. The better the material work hardening properties, the higher the limit strain. The tests show that the limit strains of AHSS in stretch bending reach their maxima at R/t ratio 1.5 ~ 2.0. This seems to be a sweet spot in the AHSS stretch bendability for product and process engineers to explore
- With large curvature bending the shell elements based on the elementary bending theory will not be able to properly predict the AHSS stretch bendability. Shell elements are not equipped to cope with the movements and separation of the neutral and unstretched surfaces during large curvature bending process
- The limit strains obtained from bending tests are not suitable for the assessments of AHSS stretch bendability

FOR MORE INFORMATION

GDIS

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