A/SP Standardization of Hole Expansion Test

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Introduction

• Newly developed AHSS have good ‘Global’ Formability (FLD, elongation, n-value)
• Concerns center around ‘local’ formability
  ➢ Bendability, ability of bending-under-tension
  ➢ Stretch flangeability, edge cracking & tearing
Introduction

- Hole expansion test is the most commonly used method to evaluate the AHSS edge cracking resistances. The standards being widely followed are
  - ISO/TS 16630 - 2003
  - JFS T 1001 - 1996
- Large variations exist in the current testing results that hamper the efforts of steel development team and OEMs to reliably evaluate the AHSS performances

Hole Expansion Ratio, \( \text{HER} (\lambda) = \frac{D_f - D_0}{D_0} \times 100 \)
A/SP STHT Team – Chrysler, Ford, GM, AK Steel, ArcelorMittal USA (AM), Nucor, Severstal NA, ThyssenKrupp USA (TKS), USS

Project objectives
- Investigate testing variations within a facility and among facilities
- Minimize testing variations with the standardization and optimization of testing tools, setups and procedure
- Develop a standard hole expansion test for NA steel and automotive industries

Phase 1 – Conduct round robin tests for 6 steel suppliers
- Study 1 – Determine the hole expansion test variations within a facility and among the facilities – 1/2013
- Study 2 – Determine the hole piercing operation variations – 5/2013
- Study 3 – Optimize the hole making method to reduce test variations – 10/2013

Phase 2 – Establish the test standard – 2/2014

Phase 3 – Standardize / commonize the testing tools, setups and procedure according to the test standard – 12/2014
Study 1: Hole Expansion Test

Parameter Diagram

Control Factors:
Control all specimen related factors such as: hole diameter, punch die clearance, die wear, die material, hole punching equipment

Input:
Six (6) materials from different suppliers with various microstructures

System
Hole Expansion Test

Output:
Hole Expansion Ratio Values/Variation

Noise Factors:
Allowed testing parameters to vary such as visual vs computer acquisition of the crack, hole expansion tools and equipment, testing speed, and material type

Symptoms:
Sample cracking on edge of expanded hole
Sampling Control

- Samples were supplied and tested by six (6) steel companies and punched by Lab 2

- Following steel with different coating and microstructures were tested:
  - DP980 GI, DP980 CR, DP590 GI, 780SF HR, 590SF HR, HSLA 420 GI

- 30 samples (4”x4”) were cut from every blank supplied by six participants

- 5 samples were cut across the coil width and length as shown above to reduce die wear effect on hole edges
Four (4) participants used digital imaging systems
Two (2) used manual method.

Representative DIS

- Opened HE machine
- Closed HE machine
- Green LED ring light
- Telecentric lens & camera
- Standard and automated tester
• The average HER values vary noticeably among the testing labs than those for the coil locations – more testing variations than material variations
• The standard deviations are smaller for each individual lab than for all labs – labs are more consistent with themselves than each other
Result Analysis

Comparison of Revised Average HER

- Average HER values obtained by the digital imaging systems and manual methods are comparable
- Digital imaging system results show better objectivity and consistency
- Findings represent small sample populations, and need to be verified with the round robin test with large sample populations
Study 2: Hole Piercing Operation

Parameter Diagram

Control Factors:
Control all specimen related factors such as: hole diameter, cutting clearance, testing speed

Input: 590SF HR and DP980 CR known to have different Hole Expansion Ratios

System
Hole Expansion Test

Output:
Hole Expansion Ratio Values/Variation

Noise Factors:
Allowed testing parameters to vary such as visual vs. computer acquisition of the crack, hole punching tools and equipment, lubrication, hole cutting speed, and material type

Symptoms:
Sample cracking on edge of expanded hole
Sampling Control

- Samples were supplied by Lab 2, punched by all participants and tested by Lab 2 (with DIS) and Lab 3 (with manual method)

- 36 samples were cut
  - from the same sheet of 590SF HR and DP980 CR, respectively
  - across the coil width and length with a similar technique used in study 1
The differences in the lab hole punching equipment and tools are identified:

- **Press** – mechanical, hydraulic; varying cutting speeds
- **Dies** – 4-posts, 2-post, C type; various tool steels
- **Method** – lubed, without lubrication
Test Results

Comparisons of Results of Different Labs

- Two different test methods (DIS - Lab2 and manual – Lab3) were used in the tests for comparison
- Noticeable differences in HER results were found for samples punched by different labs
- No clear trend is found for different hole punching operations
- Comparing with the manual test results, the digital imaging system has generated the HER results with less variations
Study 3: Optimization of Hole Making Methods

Hole punching equipment

Water-jet cutting equipment

EDM equipment

Reaming equipment
As expected, the HER values of water-jet cut, EDM and reamed holes are better than punched holes.

Best results seem to be from the punched holes tested with burr down condition.
The HER variations are smaller for high HER value samples with water-jet cut, EDM and reamed holes.

Because of surface friction and large contact areas, the samples with high expansions were stuck on the punch. The punch had to be pressed out after each test.

Instead of cracking, the edges appear failing by splitting or necking. The holes are not circular and the shapes seem to be affected by the steel anisotropy.
The edge conditions may change the failure mode from edge cracking to edge necking / splitting – an FLC type of failure.

The good edge conditions can improve the HER results. However, they do not necessarily reduce the HER variations because of the material variability / inhomogeneity.

The low HER values and variations had been obtained for the holes with run down edge conditions. In this case, the edge conditions resulting from the process have dominated the edge cracking performances.

By intuition, a “sweet spot” can exist for minimized HER variations. It would be difficult to realize it by matching the hole making methods with the materials.
Testing Conditions and Variations

Variations of HER

A set of 60 punched samples was tested with burr up and down conditions to verify the previous test.

- Burr down (Green) produces better HER values.
- The variations are not consistent. Less variation is found for burr up tests of 590SF HR. For DP980 CR, it is opposite.
On the basis of round robin test results and ISO standard, A/SP proposes a hole expansion test method to reduce the testing variations.

<table>
<thead>
<tr>
<th>Specimen</th>
<th>ISO Specifications</th>
<th>ASP Specifications</th>
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<tbody>
<tr>
<td>Dimension (mm)</td>
<td>Aim 150 x 150</td>
<td>100 x 100</td>
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<tr>
<td>Thickness (mm)</td>
<td>1.2 to 6.0</td>
<td>0.4 to 6.0</td>
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<tr>
<td>Quantity</td>
<td></td>
<td></td>
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<tr>
<td>Regular</td>
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<td>&gt; 5</td>
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<td>Qualification</td>
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<tr>
<th>Punching</th>
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<tbody>
<tr>
<td>Hole diameter (mm)</td>
<td>4-10</td>
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<tr>
<td>Clearance</td>
<td>12±1% (1&lt;2.0 mm)</td>
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<td>Tooling</td>
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<td>Punch</td>
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<tr>
<td>Die</td>
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<tr>
<td>Tooling Type</td>
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<table>
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<tr>
<th>Testing</th>
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<tbody>
<tr>
<td>Specimen Position / Burr Direction</td>
<td>Up / away from punch</td>
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<tr>
<td>Punch</td>
<td></td>
</tr>
<tr>
<td>Angle (degree)</td>
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<tr>
<td>Diameter (mm)</td>
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<tr>
<td>Material</td>
<td>No specification, HRC ≥ 55</td>
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<tr>
<td>Die</td>
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<tr>
<td>R (mm)</td>
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<tr>
<td>Dia (mm)</td>
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<tr>
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<tr>
<td>Blank Holder Force</td>
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<tr>
<td>Test Speed</td>
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<tr>
<td>Process Control</td>
<td>Visual / Camera</td>
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<tr>
<td>Test Termination</td>
<td>Thru thickness crack</td>
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<table>
<thead>
<tr>
<th>Measuring</th>
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<tbody>
<tr>
<td>Measurement</td>
<td>Caliber with resolution of 0.05mm</td>
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<tr>
<td>HER determination</td>
<td>Ave of 0 and 90 degree, Curve fitting</td>
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</table>
Conclusions

- Edges can fail in two different modes (cracking or necking/splitting) in hole expansion tests depending on the material properties and cut edge conditions.
- Results show that the testing variations can be larger than the AHSS material variations.
- Testing variations among the labs are bigger than these within a lab.
- The digital imaging system should be used for the hole expansion test because of its objectivity and consistency in inter-laboratory tests.
- The hole piercing operation has a significant effect on HER variation.
- The effects of hole piercing and expansion operations are entangled intrinsically and difficult to separate.
- Some hole making methods have improved the HER values significantly. They do not necessarily reduce the variations.
- We should minimize the testing variations. The HER results will still be affected by the material variations because of AHSS inhomogeneous microstructures.
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