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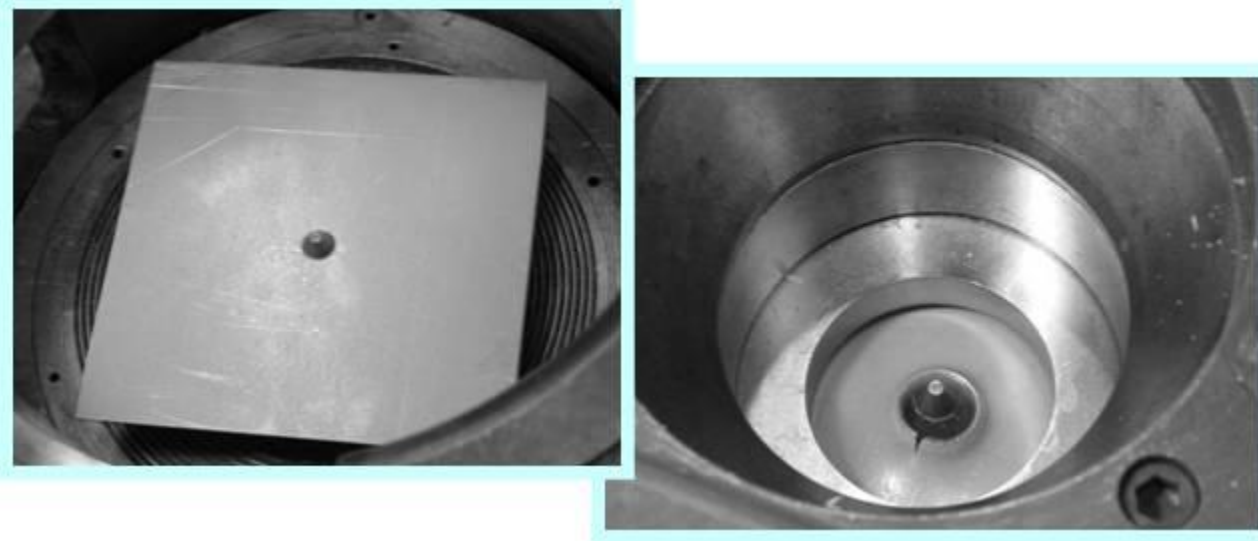
Standardization and Automation of Hole Expanding Test

Mai Huang, Liwei Zhang

ArcelorMittal Global R&D – East Chicago



Introduction



$$\% \text{ Hole Expansion Ratio} = \frac{(D_f - D_o)}{D_o} \times 100$$

Hole expanding test has been commonly used to characterize the edge cracking resistance of steels. In the past, it was primarily used in comparing steels. However, it has been increasingly used to quantify the edge cracking resistance of AHSS in recent years

Issues in Hole Expanding Test

- Larger variations are observed in the hole expanding test results. This has become an obstacle to objectively evaluate the edge cracking resistance of AHSS
- The variations are considered to come from two sources
 - *Material variations* (the properties):
The crack initiation and propagation of AHSS are related to its mechanical properties, microstructures and sheared edge conditions
 - *Experimental/testing variations* (the errors):
The errors need to be reduced or eliminated. They are caused by
 - Testing methods, setup/conditions
 - Equipment
 - Operator

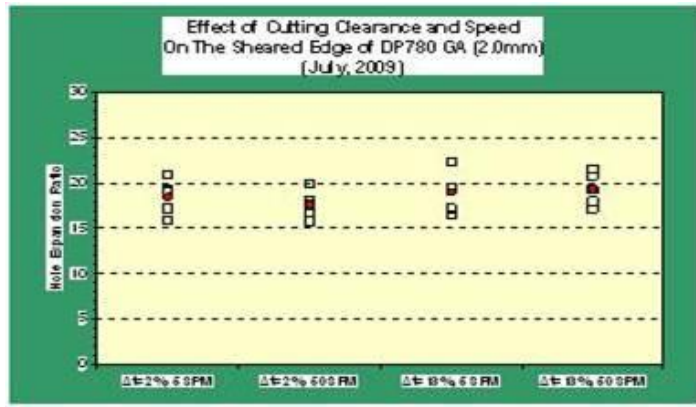


Variables in Hole Expanding Test

- The hole expanding test includes three operations
 - Hole piercing
 - Setup/conditions: cutting clearance, hole dimension
 - Equipment: tool design and materials, tool alignment, cutting speed, binder force, tool wear
 - Hole expanding
 - Setup/conditions: speed of forming
 - Equipment: sample alignment, tool alignment, binder force
 - Operator: crack observation, response time
 - Hole measurement
 - Setup/conditions: measuring directions and locations
 - Equipment: precision and calibration of measuring device
 - Operator: use of equipment



Important Findings - Hole Piercing

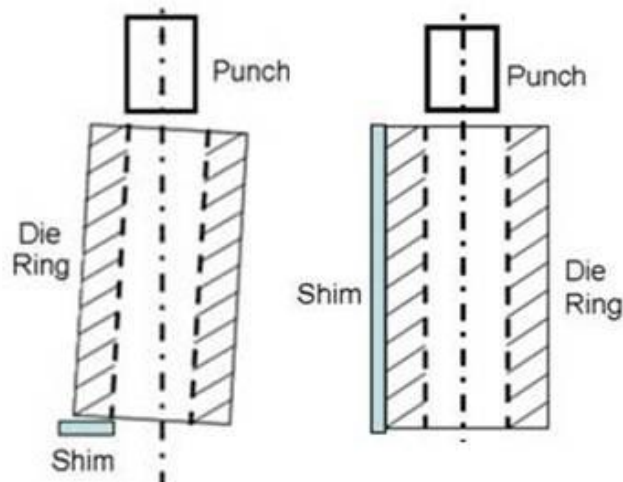


Punch Speed

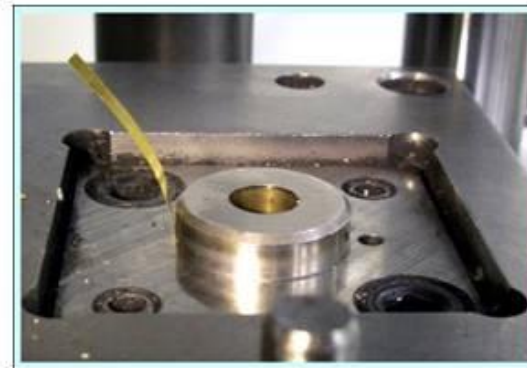
The speed used to pierce the samples was measured and varied. No significant effects found



Tool Alignment



Misaligned tool will produce uneven cut edges that may cause crack concentration



Important Findings - Hole Expanding

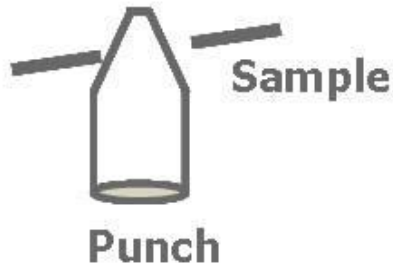


Forming Speed

The speed used to expand a sample has a significant effect on testing results

HER Values

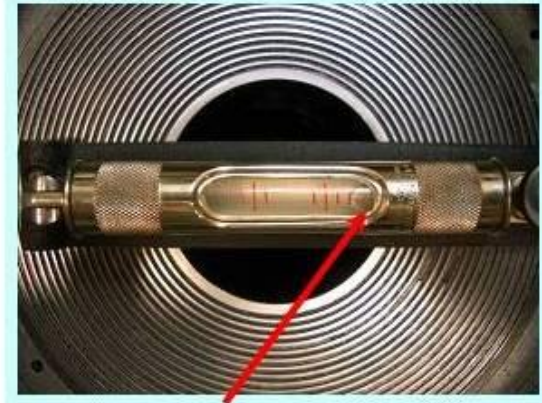
Condition	0.1mm/s	0.48mm/s	0.98mm/s	2.0mm/s
Average	68.0%	64.9%	85.2%	80.8%
Std Dev	6.6%	18.1%	15.3%	6.5%
Max. Diff.	19.3%	55.0%	40.2%	16.2%



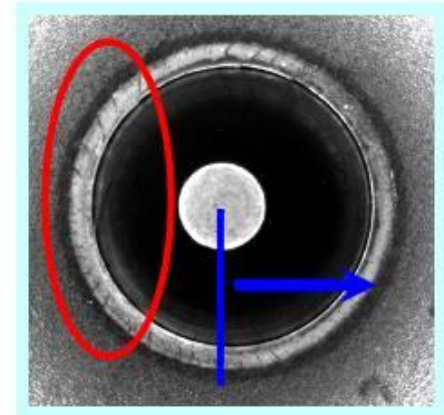
Sample Alignment

Misaligned tooling and sample would result in a crack concentration area

Tooling Alignment



Bubble



Important Findings - Hole Expanding

- Studies for variations in hole expanding operation
 - 3 operators tested 3 grades of steel in 3 consecutive sessions

Average HER Values

Test	Steel	Operator A	Operator B	Operator C	Reproducibility		
					Average	Standard Deviation	Max. Diff.
11/10 Morning	HR590	64.5%	69.2%	69.1%	67.6%	2.7%	4.7%
	T980	54.3%	51.3%	55.5%	53.7%	2.2%	4.2%
	FY350	77.5%	80.1%	81.8%	79.8%	2.1%	4.2%
11/10 Afternoon	HR590	73.4%	61.7%	65.2%	66.8%	6.0%	11.6%
	T980	56.6%	57.8%	56.2%	56.9%	0.8%	1.6%
	FY350	71.7%	81.7%	83.4%	78.9%	6.3%	11.7%
11/11 Morning	HR590	64.6%	78.9%	67.3%	70.3%	7.6%	14.3%
	T980	55.8%	61.3%	56.6%	57.9%	3.0%	5.5%
	FY350	80.9%	74.8%	78.2%	78.0%	3.1%	6.1%

The testing results showed variations for 3 operators in a test and for an individual operator through 3 sessions. Human factor has a significant effect on the experimental variations of hole expanding test



Important Findings - Hole Measurement

- Studies for variations in a hole measurement operation
 - 3 operators measured their own testing samples (3 grades of steel) in 3 sessions
 - operators remeasured the same samples a week after
 - operators measured the samples done by other operators for a cross check

Average HER

Test	Steel	Operator A			Operator B			Operator C		
		Original	A week	Diff.	Original	A week	Diff.	Original	A week	Diff.
11/10 Morning	HR590	64.5%	64.2%	0.3%	69.2%	68.5%	0.7%	69.1%	69.2%	0.1%
	T980	54.3%	54.0%	0.3%	51.3%	50.8%	0.5%	55.5%	55.5%	0.0%
	FY350	77.5%	76.9%	0.7%	80.1%	79.5%	0.6%	81.8%	81.6%	0.1%
11/10 Afternoon	HR590	73.4%	73.4%	0.0%	61.7%	61.1%	0.6%	65.2%	65.6%	0.3%
	T980	56.6%	56.6%	0.0%	57.8%	57.5%	0.3%	56.2%	56.1%	0.1%
	FY350	71.7%	71.4%	0.3%	81.7%	81.4%	0.3%	83.4%	83.4%	0.0%
11/11 Morning	HR590	64.6%	64.4%	0.3%	78.9%	78.4%	0.5%	67.3%	67.9%	0.7%
	T980	55.8%	55.6%	0.1%	61.3%	61.1%	0.2%	56.6%	57.0%	0.4%
	FY350	80.9%	80.8%	0.1%	74.8%	75.2%	0.3%	78.2%	78.2%	0.1%



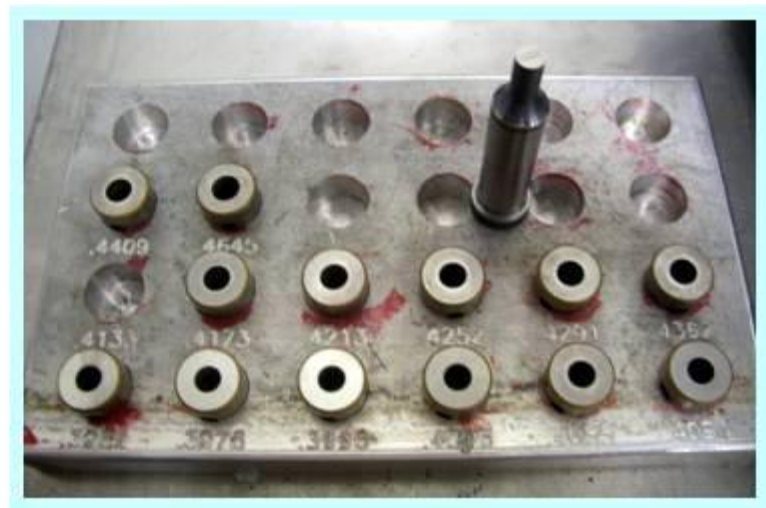
Discussions

- Based on the study of variables in a hole expanding test
 - A standardized test to eliminate and reduce the effects of variables in the testing conditions and equipment
 - Standard sample preparation and testing procedure
 - Hole piercing tool and equipment maintenance program
 - Compute-controlled hole expanding tester
 - An automated test to eliminate and reduce the effect of human factors
 - Optical strain measurement system
 - Computer program to calculate HER values for the images selected by operators (semi-automatic test)
 - Development of a computer program to identify the images with first-through-thickness cracks (fully-automatic test)



Standardization of Hole Expanding Test

- Hole piercing tooling and equipment
 - Inspecting the piercing punch and die buttons weekly. Sharpening the tools bimonthly or as needed
 - Maintaining the blank holder force by shimming the die buttons to the original height after they are ground



Standardization of Hole Expanding Test

- Hole expanding test equipment
 - Computer-controlled hole expanding tester
 - Defined forming speed (0.1mm/second)
 - Spring-loaded punch for self-centering specimens



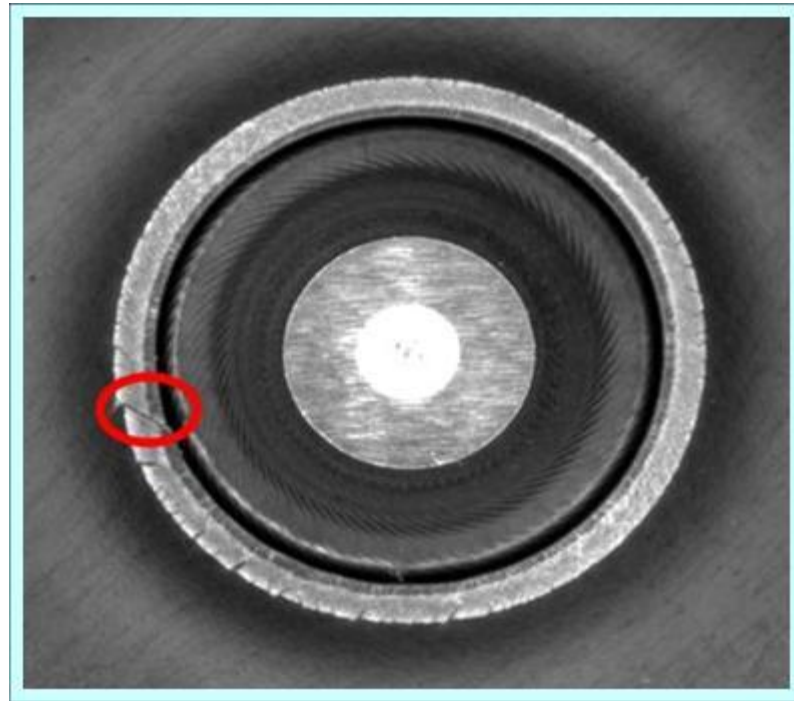
Procedure of Semi-Automatic Hole Expanding Test

- Setup camera system with proper focal length and zoom
- Start the test and record the images of deformed sample continuously
- Stop the test when operator sees the through-thickness crack
- Replay the images and manually select the image with the first through-thickness crack
- Run the program to process the image



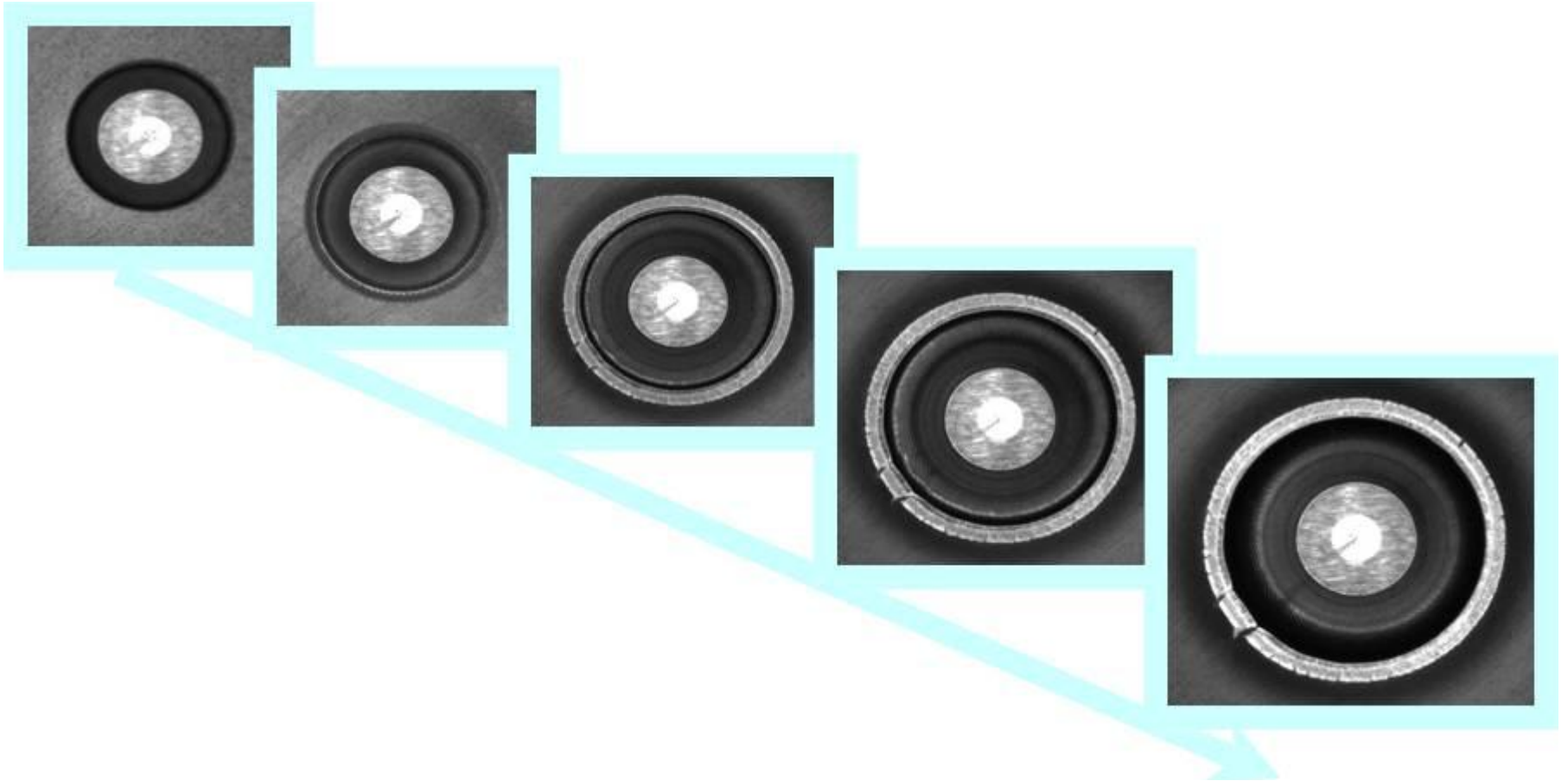
Setup of Camera System

- Setup the camera system with optimized focal length (450~600mm) and zoom (0.75x~1.5x)



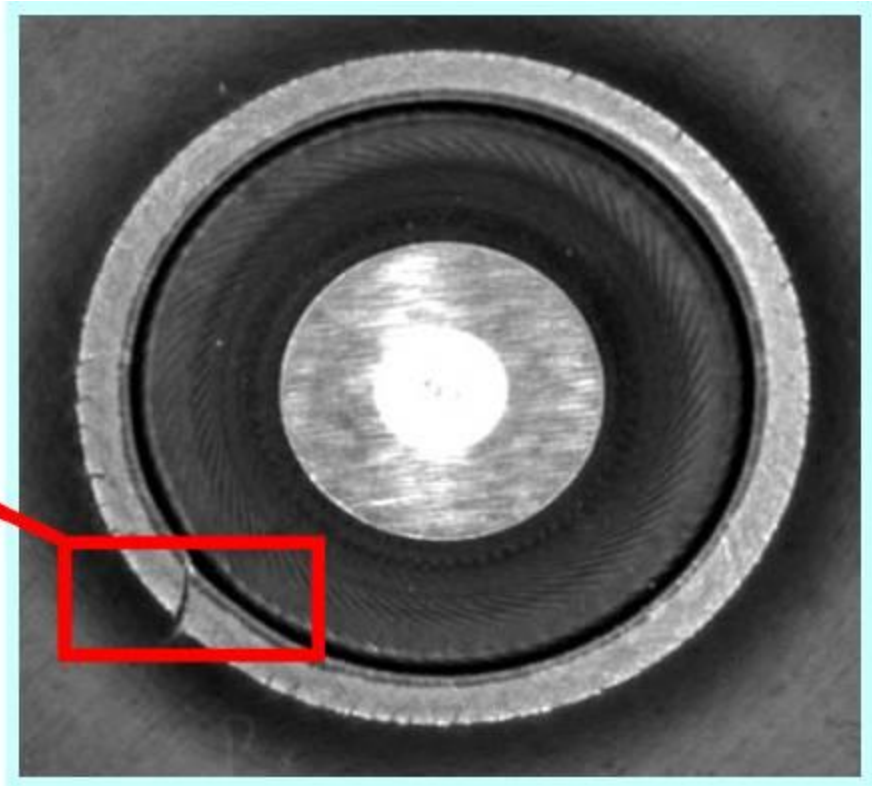
Record Images

- Take images continuously during test



Select Image of The 1st Crack

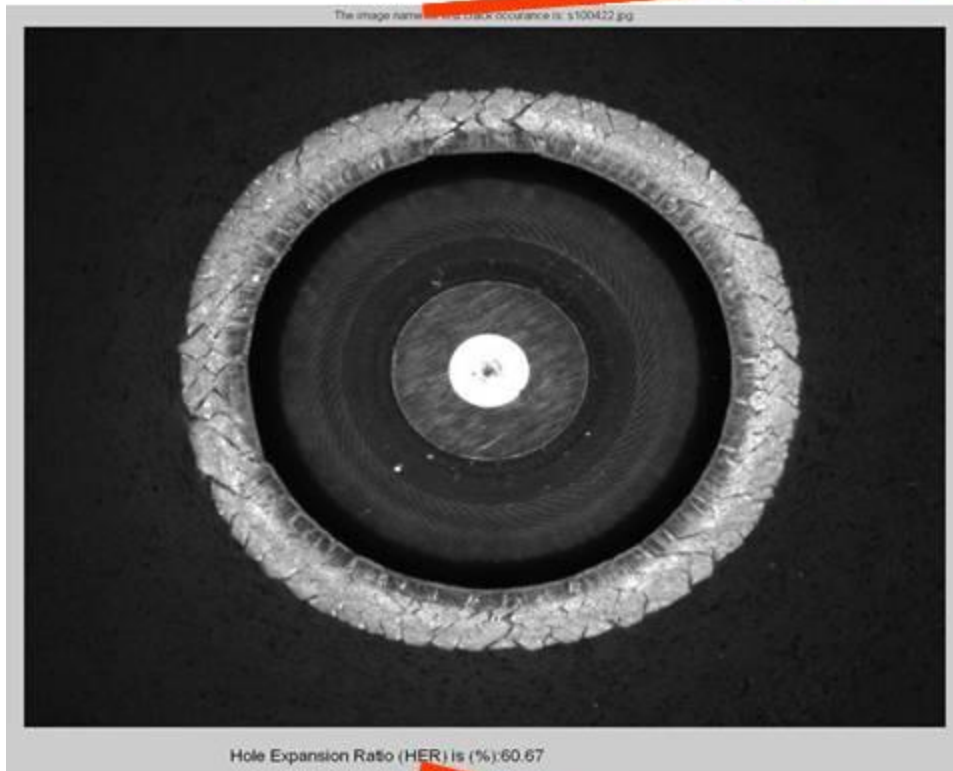
- Inspection of the 1st crack



Compute HER Value

- Calculate the HER value for the image selected

The image name for first crack occurrence is: s100422.jpg



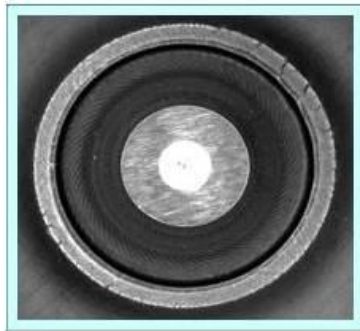
Hole Expansion Ratio (HER) is (%):60.67



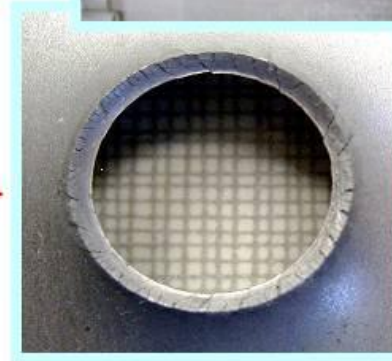
Validate the Optical Strain Measurement

- The optical HER values of the last images were verified with the sample measurements for DP590, DP780 DP980, etc.
- The HER values of last images are compared with the HER calculated for the images with first-through thickness cracks

	Sample #	Optical		Physical
		First Crack	Final Shape	Final Shape
DP980 GA (2.0mm) 4/9/09	1	17.3	22.6	22.4
	2	13.0	15.8	15.5
	3	20.4	21.6	22.0
	4	18.0	19.2	19.2
	5	19.5	19.9	20.2
	Average	17.6	19.8	19.8
	Stdev	2.9	2.6	2.8



Optical Measurement



Physical Measurement

Summary

- The standard hole expanding test that includes a is established
- The optical imaging system to capture and record the images of deformed specimens during hole expanding test is installed
- A semi-automatic hole expanding test (operator selects the image for HER calculation) is established
- A standardized and fully automated hole expanding test (computer selects the image for HER calculation) is under development



Question & Suggestion

