

# Importance of hole punching conditions during Hole Expansion test

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**Abstract.** There is an increasing interest in the steelmaking and automotive industries to evaluate the edge cracking sensitivity of Advanced High Strength Steel sheets used in car body manufacturing. Currently, the Hole Expansion test is the only test procedure that is defined by norms (JFS and ISO). This test is increasingly used to assess the formability of cut-edges on punched sheets because it is relatively simple. However, it has been already shown that there can be large differences in Hole Expansion Ratio (HER) values generated by different testing facilities. Among the main sources of variability: punched hole quality and hole expansion termination point. Hole punching operation has a detrimental effect on cut-edge quality and HER values. However, current standards do not give any recommendation. No technical specification is given for the tooling, quality control system and punching speed. It has been stated that the press speed difference in the hole punching operation are significantly different from one laboratory to another one and some steel microstructures sensitive to it. However, very few papers and data are available. As a result, an experimental study was conducted to examine this important issue. A specific 4-post assembly tool was designed to guarantee the best punched hole quality. Different punching speeds, from 0.2mm/s to 367mm/s were tested on different steel sheets (mild steel, AHSS including TWIP and 3<sup>rd</sup> Gen steel) to emphasize or not the influence on final HER values.

## 1. Introduction

In the automotive industry of sheet metal forming, the operations based on trimming, shearing and punching are still the most used cutting processes due to their speed, simplicity and cost. These mechanical cutting processes reduce the residual formability of any steel blank edges. The use of AHSS becomes challenging for parts manufacturers, because after cutting they present limited ductility compared to conventional mild steels.

Lots of tests have already been developed to assess the stretch flangeability of sheet metal [1]. In spite of all these proposals, the conical Hole Expansion test remains the most common used trial to assess the formability of cut-edges and HER values have become an important parameter to consider in AHSS sheets formability. It is the only “Cut-edge” test to be defined by standards [2] and [3]. However, current standards are always discussed. Hayashi was certainly the first to highlight the different influencing factors on Hole Expansion limit and the necessity to define a standard [4]. Lots of work were done to examine various factors in the Hole Expanding test [5] and [6]. The large variations in the testing results have caused the concerns of several steel product development people and testing engineers [7]. Among the main sources, two can be highlighted: the punched hole quality



and the hole expansion termination point. The second point relies on the ability of the operator to stop the test when a through thickness crack appears on the edge of the punched hole. It is not the matter of this paper since lots of progress have been already made like the use of a video recorded image coupled with automated HER measurements [6] and [7]. Hole punching operation has a detrimental effect on HER values. The characteristics of the cut edge around the hole will be completely different from bulk material. It will be damaged, hardened and some defects, such as micro-cracks, can be present. [8] and [9] investigated the consequences of hole punching operation on final cut-edge ductility. Up to now very few analyses or guidelines regarding the hole punching operation itself were published. Current standards do not give any recommendation (no details about the punch and die tooling, quality control system and punching speed). However, it was stated that the press speed in the hole punching operation is significantly different from one laboratory to another one and that some steel microstructures are sensitive to it. [10] studied the effect of punching speed on HER for a wide variety of steel grades. No or insignificant effect on local formability was observed. However, the punching speed was only compared at 1mm/s and 25.4mm/s which is far from industrial conditions where stamping / shearing speeds are commonly found to be in the range of 150 to 300 mm/s. [11] also observed no influence of the punch speed on sheared geometries and blanking forces within the tested range of [30 mm/s; 100 mm/s] on press hardened UHSS. However, [12] shows that the edge formability increases dramatically after hole punching  $\geq 28$  mm/s on NanoSteel 3<sup>rd</sup> Gen AHSS with very specific refinement and strengthening mechanism.

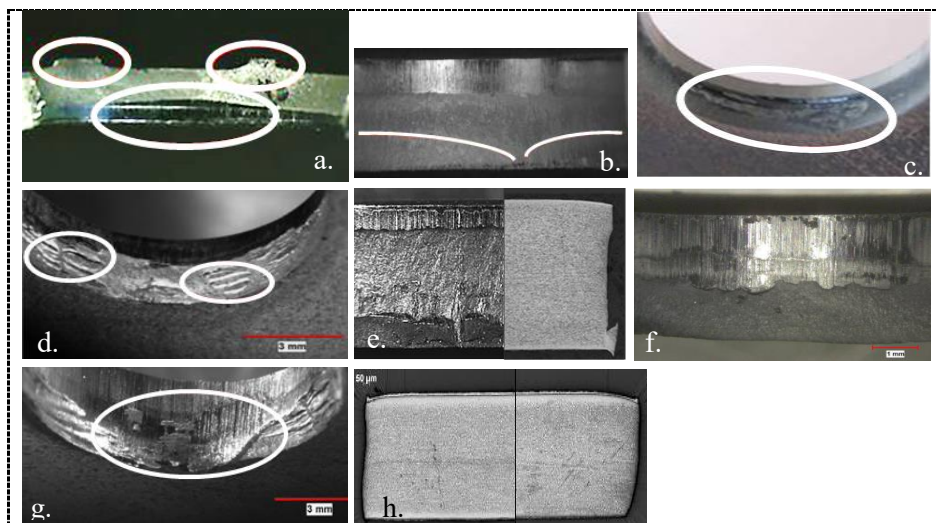
As a result, the effort was made on the hole punching conditions. First, a specific 4-post assembly tool was designed to guarantee the best punched hole quality and the best consistency on HER. Then, the influence of the hole punching speed was investigated in a wide range of speeds [0.2 - 367mm/s]. Different steel grades including mild steel, existing AHSS and 2<sup>nd</sup> and 3<sup>rd</sup> Gen steels were tested.

## 2. Design of a specific 4-post assembly tool for hole punching

### 2.1. Examples of bad cut-edge quality and hole punching conditions

Non-optimal hole punching conditions lead to edge defects which will significantly reduce the HER values and increase the experimental errors. They are mainly due to a poor tool alignment, an improper tool clearance, dulled and/or chipped punching tools or a poor parallelism between punch and sheet. The following examples (Figure 1) are intended to provide some references or alerts for operators to check the edge defects and assure the qualities of HER values:

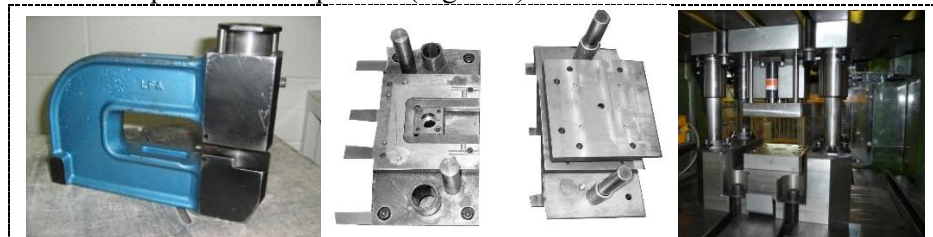
- Variable Burnishing and local excessive burr (a.): occasionally, the sizes of sheared and fracture zones can vary locally from one point to another. The excessive burr is probably caused by a defect on punch or die punching tools or by a tooling-sample misalignment.
- “V-shape” on fracture zone through thickness (b.): it could appear when the contact between tools and sheet is non uniform (misalignment, local defects on tools).
- Grooves in fracture zone (c.): characterized by the darker patches in the lighter toned fracture zone, these grooves are often found when the clearance is set too high.
- Parallel cracks in fracture zone (d.): usually benign as hole expansion will compress the cracks, rather than propagate them. Often due to a poor alignment or inappropriate clearance.
- Double shearing zones (e.): it appears especially when cutting clearance is too low.
- Jagged boundaries between the sheared and fracture zones (f.): it indicates a non-uniform tooling contact in punching. Potential causes are the poor tool alignment, improper clearance setting, or deterioration of tool cutting edges.
- Smearing (g.): this is a sign of tool contact during the punch travel. It is normally caused by the improper cutting tool clearance and alignment.
- Abnormal edge profiles (h.): Abnormal edge profile can happen due to various reasons, such as the improper cutting tool clearance, poor alignment and equipment irregularities.



**Figure 1.** Overview of different cut-edge defects after hole punching

## 2.2. Comparison of different tools used for hole punching

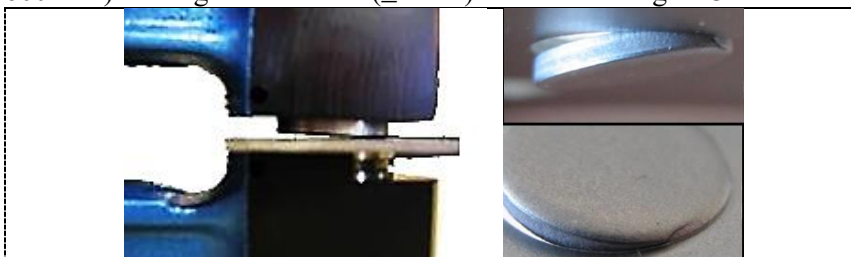
The hole punching operation is made differently by one laboratory to another one. Different machines can be used, like for example uniaxial tensile machine or mechanical or hydraulic presses. Different types of punching tooling are also used. They can be summarized as 1- or 2- or 4-post assembly tool excluding all in-house specific developments (Figure 2).



**Figure 2.** 1-, 2- and 4-post assembly tool

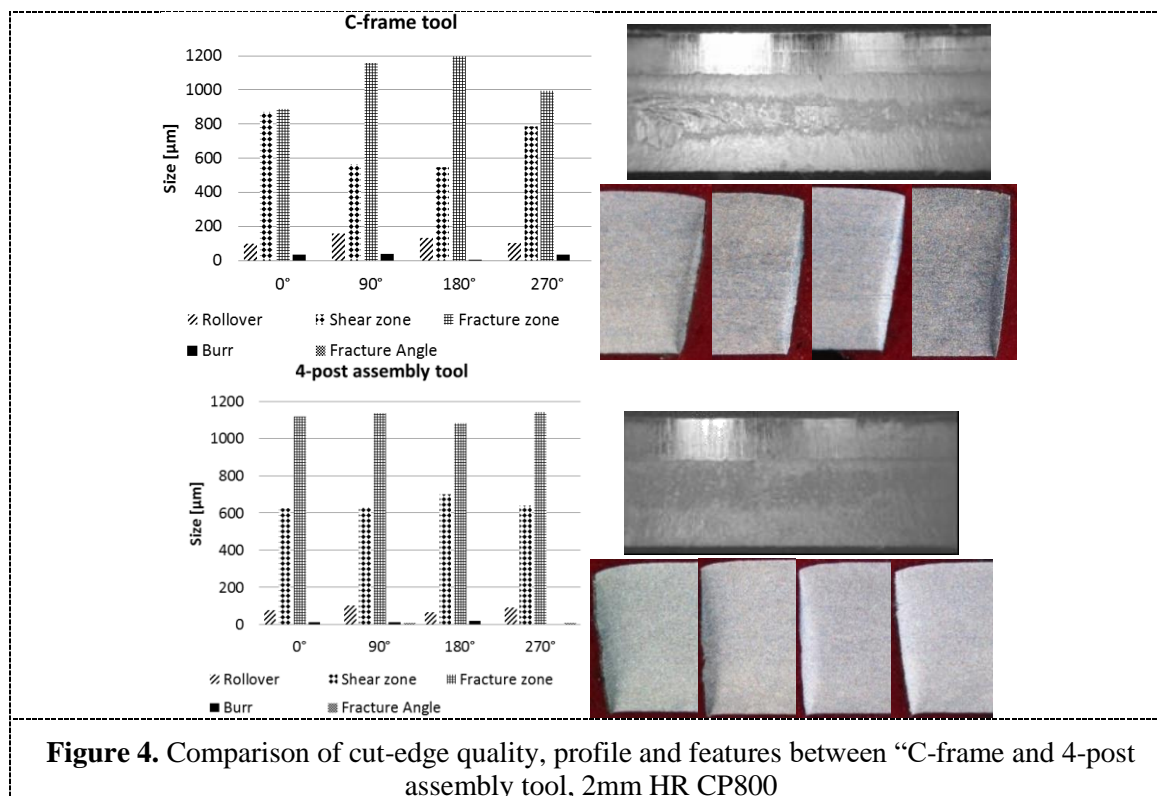
### 2.2.1. Advantages of a 4-post assembly tool compared to other ones

The limits of a 1-post assembly tool (also named “C-frame” tool) are quickly reached when working with AHSS ( $\geq 600\text{MPa}$ ) and high thicknesses ( $\geq 2\text{mm}$ ) as shown in Figure 3.



**Figure 3.** Too low stiffness of a C-frame tool leading to non-homogeneous cutting with AHSS

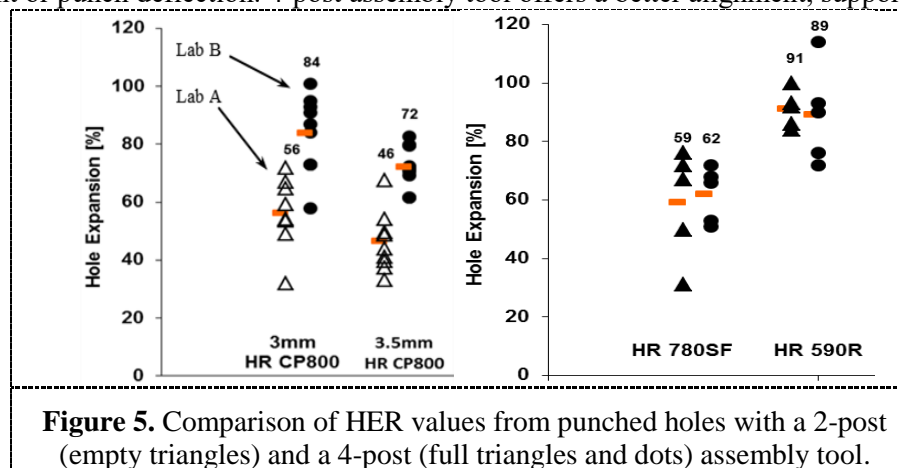
Compared to a 4-post assembly tool, the cut-edge features (size of the Rollover, Shear and Fracture zones) after punching with a “C-frame tool” are not homogeneous all around the hole (Figure 4).



**Figure 4.** Comparison of cut-edge quality, profile and features between “C-frame and 4-post assembly tool, 2mm HR CP800

A 2-post assembly tool also reveals to be inappropriate as illustrated on Figure 5. Two laboratories performed hole expansion tests. Laboratory A was first equipped with a 2-post assembly tool and got significantly lower HER values compared to laboratory B. A manufactured a 4-post assembly tool and carried out new cross-trials with B. HER values become consistent.

1- or 2-post assembly tool usually result on subtle differences on cut-edge quality due to rocking, misalignment or punch deflection. 4-post assembly tool offers a better alignment, support and rigidity.



**Figure 5.** Comparison of HER values from punched holes with a 2-post (empty triangles) and a 4-post (full triangles and dots) assembly tool.

### 2.3. Design of a specific 4-post assembly tools for hole punching

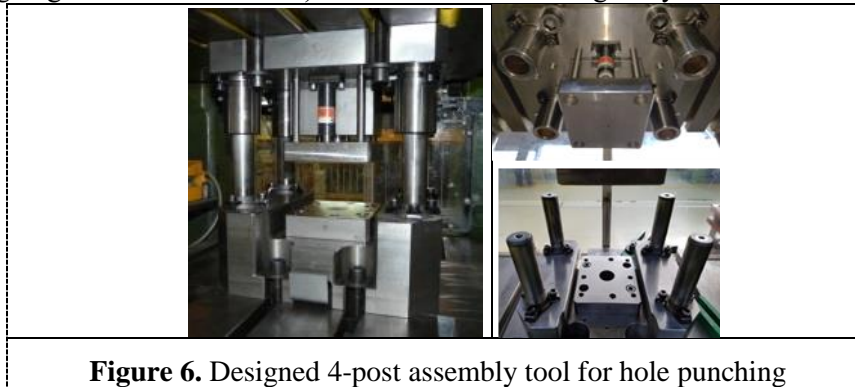
ArcelorMittal R&D Maizières designed a specific 4-post assembly tool (Figure 6) to get a punched hole quality expected to be as best as possible i.e. consistent over time and allowing reliable and effective for AHSS edge cracking resistance assessment. There is no technical specification available into current standards for hole punching tool manufacturing like die design, fabrication method, tooling materials, assembly tolerances, etc. However, the following issues should be considered:



1. Global tool: definitively a 4-post die is recommended since it provides a better alignment than any other systems under a heavy punch load. The tooling alignment is the most important point. It ensures a properly set and evenly distributed cutting clearance.

2. Punch / die set and holder systems: the ball-lock punch seems unable to maintain its alignment. The tolerance between the current ball-lock punch and punch holder is relatively loose because of the tool construction. In order to do a quick tool change, the punch holder is designed to lock the punch by a spring loaded ball. Consequently, a comparatively large clearance exists between the punch and punch holder and the punch can wiggle under a heavy load. This may lead to an uneven punch cutting clearance and varying hole edge characteristics. A press-fit M2 or M4 punch and M2 die rings are recommended for the tool rigidity and alignment.

3. Other parameters: the tooling height should be adjusted to enable the piercing punch to cut the specimens with maximum force, the punch cut edge should travel through the sample thickness, but no more than 3mm beyond the burr, a tooling maintenance program and tooling inspection (cut-edge quality, tooling alignment and cleanness) should be conducted regularly.



**Figure 6.** Designed 4-post assembly tool for hole punching

### 3. Effect of hole punching speed

Significant differences between different laboratories performing hole expansion test can be observed from 0.4 mm/s to 187 mm/s. Up to now very few papers analysed hole punching speed effect ([10], [11] and [12]) but analyses were made on specific and restricted conditions (low range of punching speed and/or specific steels). As a result, investigations in a wide range of speeds (from 0.2mm/s to 367mm/s) and steel products were launched.

#### 3.1. Materials

Different steel grades including conventional steel, existing AHSS, and emerging TWIP steel and 3<sup>rd</sup> Gen steels were tested. Mechanical properties are shown in Table 1.

**Table 1.** Mechanical properties of tested materials.

	Thickness [mm]	Yield Stress [MPa]	Tensile stress [MPa]	Total Elongation [%]
<b>CR HSLA460</b>	1.5	482	597	21
<b>HR CP800</b>	1.8	761	861	14.2
<b>CR DP780</b>	1.4	532	798	19.7
<b>CR 2<sup>nd</sup> G (TWIP)</b>	1.3	>600	>1000	>50
<b>CR 3<sup>rd</sup> G</b>	1.2	>600	>980	>19

#### 3.2. Experimental procedures

Five square specimens (100mm x 100mm) were blanked from the different steel sheets. They were randomly picked for an individual hole punching operation. A Ø10mm hole with a cutting clearance close to 12% was punched on each specimen with the 4-post assembly tool and different machines to

reach the expected punching speeds. Finally, hole expansion tests were performed according to the ISO-16630 standard.

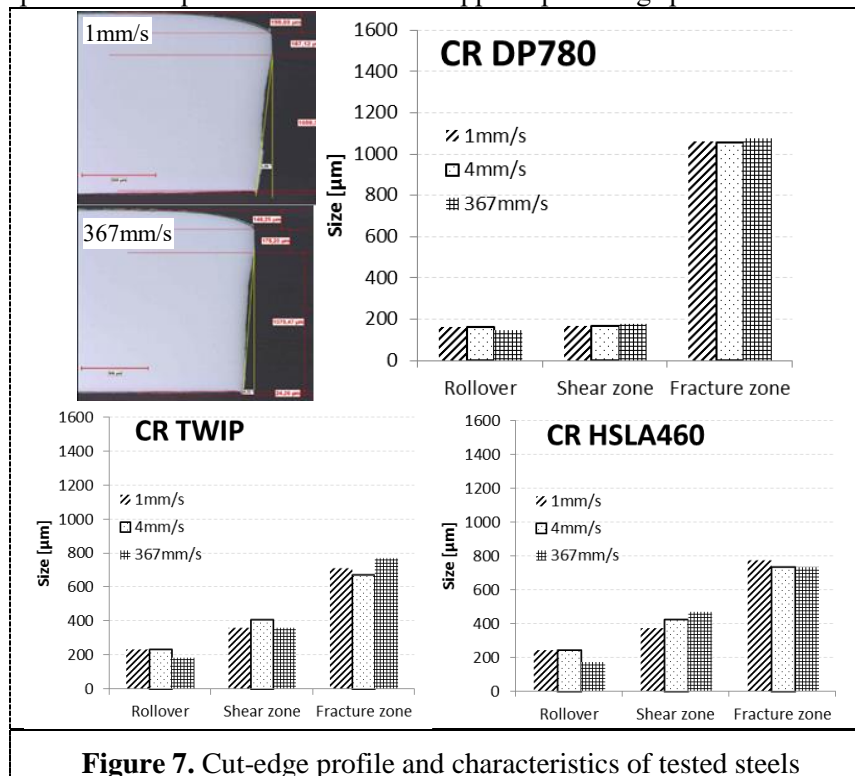
### 3.2.1. Hole punching operation

To reach defined punching speeds, three types of machine were used (Table 2).

**Table 2.** Hole punching operation conditions.

	Zwick100 tensile machine	Bliss 0.8MN press	Bruderer BSTA60 press
<b>Energy power</b>	Mechanic	Hydraulic	Hydraulic
<b>Tested speed [mm/s]</b>	0.2/ 0.5/ 1/ 4	20	227/ 367

For each punching speed, the 4-post assembly tool was mounted on the different machines. A 12% cutting clearance was respected according to the ISO-16630. The cut-edge profiles at the different punching speeds were compared. No significant differences on cut-edge characteristics are observed (Figure 7). The profiles are equivalent whatever the applied punching speed.



Micro-hardness measurements (HV0.1) were carried out to highlight possible differences of hardening according to the hole punching speeds (Figure 8). No significant differences on  $\mu$ -Hardness measurements were observed except for TWIP steel for which, values at 367mm/s are lower on the Shear zone. [8] highlighted that the work hardening induced by the punching process present in the shear zone governs edge cracking resistance. High induced work hardening reduces cut-edge formability. In this case, all products except the TWIP grade show the same level of  $\mu$ -Hardness values in the shear zone. For the TWIP steel, a decrease of  $\sim\Delta 90$  HV0.1 was observed between 1mm/s and 367mm/s. Consequently, higher HER could be expected.

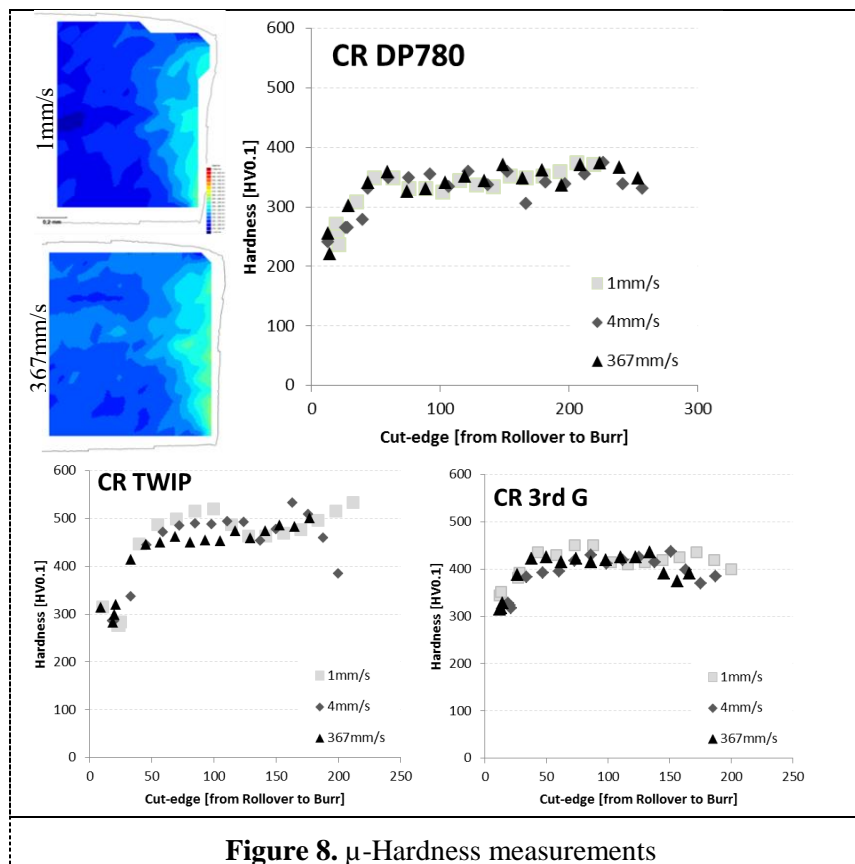


Figure 8.  $\mu$ -Hardness measurements

### 3.3. ISO-16630 Hole Expansion test

Punched holes were expanded according to the ISO standard. Since results greatly depend on the perception and reaction speed of the operator, the tests were conducted by the same experienced person to minimize the effect. The results are plotted in Figure 9. Punching speed effects seem insignificant on HER values except for TWIP steel.

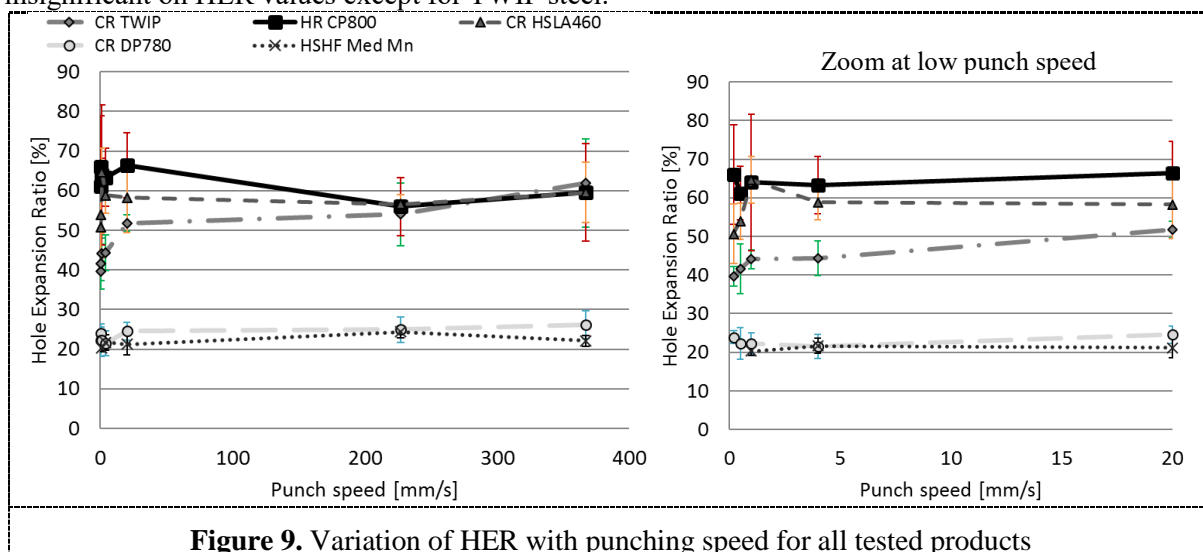


Figure 9. Variation of HER with punching speed for all tested products

No difference was observed on crack initiation (same number and shape of cracks). At lower punching speeds ( $\leq 20$  mm/s), TWIP steel already shows an increase of HER values with higher

punching speeds. For HSLA460, HER values increase from 0.2mm/s to 4mm/s and then they reach a plateau. A peak is reached at 1mm/s without any explanation until now.

#### 4. Summary / Conclusions

Hole punching is a key operation for Hole Expansion test, the hole edges characteristics and HER values are strongly affected by the hole punching quality. However, current standards do not give any recommendation about it. There is no technical specification available for the tooling, quality control system and punching speed. Investigations were launched to bring some recommendations about hole punching operation and more details about the effect of punching speed.

It appears that a 4-post assembly tool is the best tooling for hole punching operations. It offers the best possible alignment, support and sufficient rigidity. and ensure a punched hole quality consistent over time to make reliable and effective edge cracking resistance assessment for AHSS. No effect of punching speed was observed for all tested products except TWIP steel. In this case, the edge formability increases gradually with the punching speed (+ 22% in HER value).

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