A Study on Effects of the Press Speed on Sheared Edge Formability

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Abstract. In this study, the effect of shearing speed on edge formability was investigated with two different grades of advanced high strength steel (AHSS), DP780 and GEN3-980. A straight blanking tool with adjustable shear clearance was used to shear the selected materials in two different type presses, a high-speed pneumatic press, and a mechanical servo-press. The four different shearing speeds from 0.01 meter per second up to 1.5 meters per second were realized and measured. The different shearing speed conditions result in different edge quality and work hardening levels. The half specimen dome test and micro-hardness analysis were conducted to evaluate the edge formability. The samples sheared with a pneumatic press at a higher speed showed significantly better edge quality, less hardness increase, and smoother sheared edge than the samples sheared with the servo press. The developed high-speed shearing condition has a very good potential to shear AHSS without creating significant damage and work hardening on the sheared edge, providing further advantages for the post stamping operations.

1. Introduction
The edge cracking issue has been observed in the sheet metal stamping process, especially in the advance high strength steels (AHSS). The edge cracking does not typically follow the forming limit diagram or other failure criteria during forming. As more AHSS has been considered for the lightweighting of motor vehicles, the edge cracking issue needs to be addressed. Various studies have been done to evaluate and improve the sheared edge quality of AHSS.

To evaluate the factors that influences the edge local formability, the effect of die clearances has been reported by Henderson et al. [1] and Lee et al. [2]. The critical parameters that influence the local edge formability was investigated by Pathak et al. [3] The study concluded that the sheared edge formability was influenced by the edge work hardening.

Interestingly, a recent finding by Fraunhofer IWU has shown that through high-speed impact shearing, the pierced hole has a much smoother surface than the conventional hole piercing process [5]. The mechanism behind this could be the adiabatic softening effect from the high-speed impact. However, little research has been done on the effect of formability in various shearing speed. Therefore, a study on the influence of different shearing speed on the edge local formability was conducted at EWI.

2. Sample preparation
2.1. Test matrix
This study was conducted with two AHSS materials, DP780 and GEN3-980. The material properties are given in table 1.
Table 1: Material properties of the selected sheet metal

| Material       | Thickness (mm) | Yield Strength (MPa) | Tensile Strength (MPa) | Total Elongation |
|---------------|----------------|---------------------|------------------------|-----------------|
| DP780         | 0.9            | 499                 | 855                    | 18.0 %          |
| GEN3-980      | 1.2            | 609                 | 1022                   | 22.1 %          |

Each material was sheared using the same test tooling with four different die clearances and four shear speeds. The shear die breakages are adjusted by the percentage of the material thickness. The shear die can be adjusted with different shim combinations to accommodate different material thickness and different shear clearances.

The edge local formability of the sheared sample was be evaluated using HSDT, microhardness test and optical microscopy. The test matrix is shown in table 2.

Table 2: Test matrix of shearing test and edge evaluation

| DP780  | GEN3-980 | Shearing speed | Repetition             |
|--------|----------|----------------|------------------------|
|        | Shear clearance % | Shearing | HSDT | Hardness test and Optical Microscopy |
| 9% a   | 9%       | 4             | Minimum 5 | Minimum 3 | 1 |
| 12%    | 11%      | 15%           | 18%        |

a. Shear clearances are calculated by $\text{Shear clearance}\% = \frac{\text{Die clearance}}{\text{Material thickness}} \times 100\%$

b. This condition was sheared

2.2. Shear test

Each material was sheared with four different press speeds using AIDA 300-ton servo press and AIRAM 12-ton pneumatic press using the same set of tooling shown in figure 1. Two press motions, silent deceleration and crank motion, were used in AIDA servo press, shown in figure 2. Crank motion imitates the production of conventional mechanical blanking press using 20-spm press setting, while silent deceleration decelerates the ram to 10% initial speed of the crank motion before initial contact of the blank. Two pressure settings of the pneumatic press, 30 psi and 50 psi, were used to provide the shearing speed up to 1.8 m/s. The speed of the pneumatic press can be adjusted by changing air pressure setting.

![Figure 1. Servo-press (left), pneumatic press (middle) and shear test tooling (right)](image-url)
The instantaneous shearing speed of the servo press was provided by the servo control module. The displacement and speed vs time of the two different press motions are shown in figure 2. For the pneumatic press, the speed was measured by a laser sensor with 1000-Hz measuring frequency. An example of the press motion and speed measurement is shown in figure 3. The shearing speeds of all press options were measured when the shear die makes initial contact with the blank.

![Figure 2. AIDA servo-press speed and position vs time of crank motion and silent declaration](image)

![Figure 3. AIRAM pneumatic press position vs time and speed measurement](image)

The measurement of average press speed and standard deviation are shown in table 3. The silent deceleration press motion carries less than 10% the speed of crank motion, while the pneumatic press motion has about 10 times the speed of the crank motion.

### Table 3: Shearing speed measurement at tooling contact for each press motion

| Press motion   | Speed (mm/s) | St. dev |
|----------------|--------------|---------|
| Servo-press    |              |         |
| Silent deceleration | 12.7      | 0.3     |
| Crank motion   | 144.7        | 1.6     |
| Pneumatic press|              |         |
| 30psi-AIRAM    | 1283.1       | 142.2   |
| 50psi-AIRAM    | 1810.7       | 245.8   |

3. Evaluation of the sheared edge quality

3.1. Half Specimen Dome Test (HSDT)

An alternative method, HSDT, was conducted to evaluate the edge local formability. HSDT was extensively developed and evaluated by Kim et al. [6] and Gu et al. [7]. Different from the ISO standard hole expansion test, HSDT can evaluate the stretchability of a straight sheared edge. The test sample was sheared into a 100-mm by 200-mm rectangular shape with the interested sheared edge on the length of the rectangle. The 100-mm diameter Nakajima punch was used in HSDT to expand the sheared edge.
3D-DIC was used to capture the strain fields of the sample. The tooling setup and example of strain field post processing are shown in figure 4.

The dome punch expands the edge and creates stress concentration at the sheared edge between the apex of the dome and the die, without contact to the tooling. The DIC captured equivalent strain at the onset of edge cracking was used as main criteria to evaluate the sheared edge formability.

![Figure 4. HSDT setup, HSDT tested sample, and DIC strain contour](image)

3.2. Microhardness and Optical Microscopy
The hardness of the shear affected zone can be measured using a microhardness test. The edge hardness was compared to the base metal hardness. The sample was cut in the cross-section direction, mounted and polished. A microscopic image of the edge topography was also captured during the hardness test.

Ten indentations were made from 0.10 mm from the edge and has index distance of 0.15 mm from each other to affect the interference of the shear field from the indentation. The starting point of the hardness measurement is indicated in figure 5. The hardness measurement has the first indentation at the transition of burnished zone and fracture zone, where the highest hardness value is usually observed along the thickness direction.

![Figure 5. Starting point selection of hardness test](image)

4. Results and Discussions
4.1. Half specimen dome test result
Figure 6 shows the summary of equivalent strain at the onset of cracking for the sample sheared with different clearances and in different speed. Higher equivalent strain indicates better edge formability. In each shear clearances for both materials, the higher two shearing speeds, 1283 mm/s and 1811 mm/s, show higher equivalent failure strain compared to the lower-speed cases. In the lower speed cases, silent deceleration (12.7 mm/s) shows slightly worse edge stretchability. Overall, the high-speed cases show improved edge failure strain compared to the conventional and low speed cases, but the result cannot differentiate a preferred case in the two high-speed settings.
Figure 6: HSDT equivalent strain in each shear clearance and speed combination.

4.2. Microhardness measurements
An example of the microhardness of DP780 and GEN3-980 is shown in figure 7. The first hardness at the edge shows the highest value and the hardness decreases and approaches base metal hardness. The hardness measurement in other clearance and shearing speed combinations follow a similar trend. The measurement from the first indentation is identified as the critical edge hardness that represents the work hardening level at the sheared edge. The normalized critical hardness was calculated by equation 1. Higher normalized hardness indicates higher work hardening induced from shearing process.

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\text{Normalized Critical Hardness} = \frac{\text{Critical hardness}}{\text{Base metal hardness}} \tag{1}
\]
Figure 7. Microhardness measurement of DP780 with 9% shear clearance and GEN3-980 with 15% shear clearance

All combinations of normalized critical hardness with different shear clearances and speeds are summarized in figure 8. Although either within the two higher speed settings or the lower two speed settings, the preferred case varies depending on the shear clearances. It is clear that the sample sheared with higher speed from pneumatic press shows lower normalized hardness. For both materials, the sample produced by pneumatic press with high-speed shearing shows lower work hardening, which indicates preferred edge condition.

Figure 8: Critical normalized hardness of each shear clearance and speed combination

4.3. Optical microscopy
The optical microscopy images were taken for each shearing conditions to qualitatively evaluate the edge quality. Figure 9 shows an example of the DP780 sheared in different speeds with 11% die clearance. Both materials show similar edge profile. The sample sheared with the two press settings from pneumatic press have a smooth transition between burnished zone and fracture zone, as well as minimal rollover zone and burr.
Figure 9: Optical microscopy images of DP780 material sheared with 11% die clearance in different speeds

5. Conclusions
The following conclusions can be drawn from this study:

- Sheared edge quality can be significantly influenced by shearing speed. With all clearances, the sample sheared with a high-speed process using pneumatic press shows improved sheared edge local formability.
- From optical microscopy analysis, the sample sheared by both high-speed settings of the pneumatic press shows minimal rollover height, smoother sheared surface and negligible burr. The topography of the edges sheared in high speed is different from lower shearing speed using servo press.
- The preferred shear clearances vary with different speed settings. The preferred shear condition for DP780 and GEN3-980 are:
  - DP780: 1283 mm/s shearing speed with 15% die clearance (92% higher HSDT failure strain than that of crank motion average)
  - GEN3-980: 1810 mm/s shearing speed with 9% clearance (50% higher HSDT failure strain than that of crank motion average)

6. References

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