A Comprehensive Study of Hole Punching for AHSS

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1. AK Steel Corporation
2. FCA USA LLC
3. General Motor Company

AK Steel

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Outline

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  - Tool Setup
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  - Tool Protections
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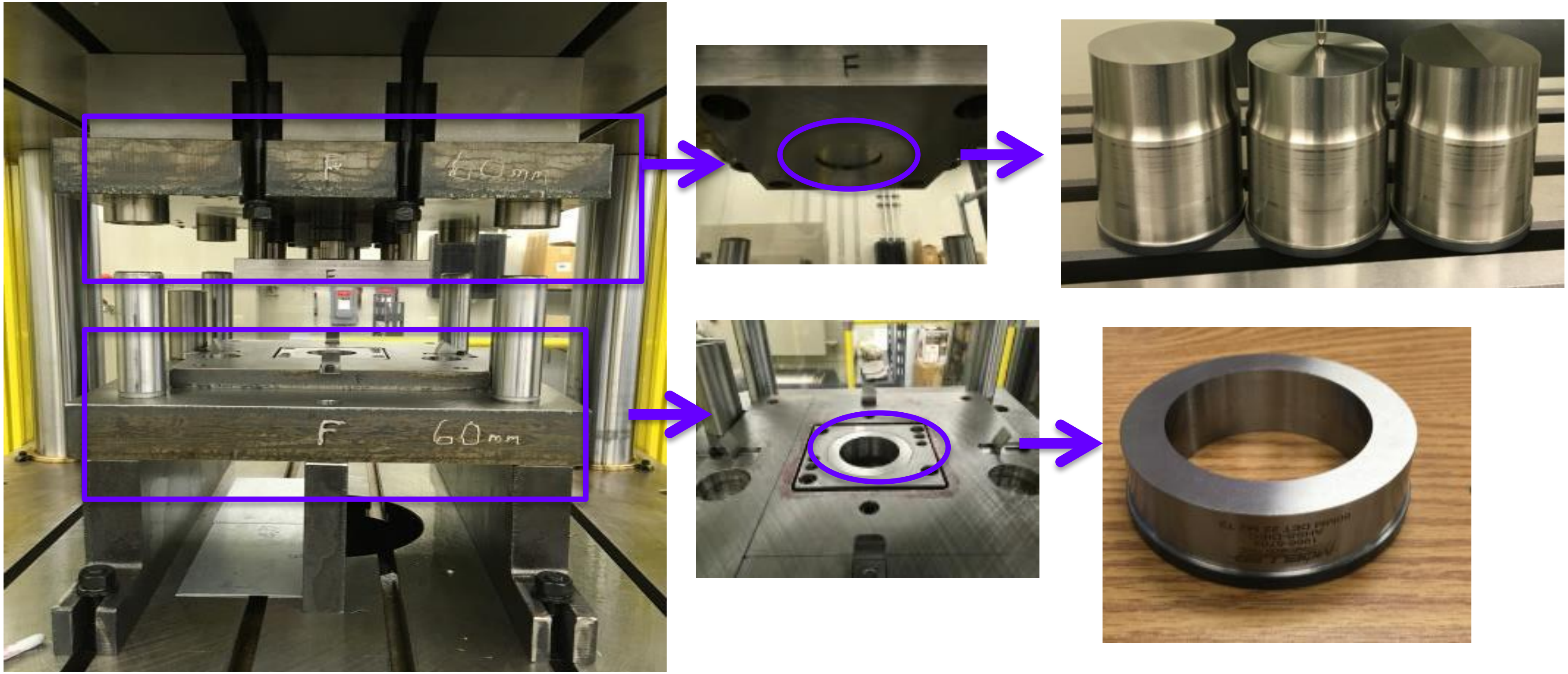
Introduction

Hole Punching on AHSS

Image source : Stamping Journal, March, 2014

- Punching Force Reduction
- Dimensional Accuracy
- Tool Protection
- Edge Quality

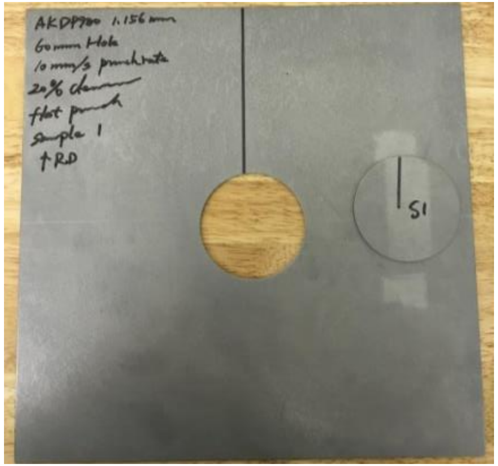
Experimental Tool Setup

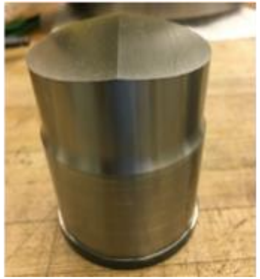


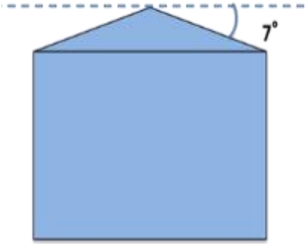
Experimental Variables

- Sample size: 254mm×254mm
- Punch rate: 10 mm/s
- Punch shapes: flat, conical, rooftop
- Punch tipping angle: 7°

Material	Thickness (mm)	Nominal Punch Clearance
DP 1180	1.20	6.0%, 12.0%, 20.0%
DP 980	1.16	6.2%, 12.5%,20.8%
DP 590	1.31	6.4%, 12.8%,21.4%
DDS	1.38	6.1%, 12.2%,20.3%

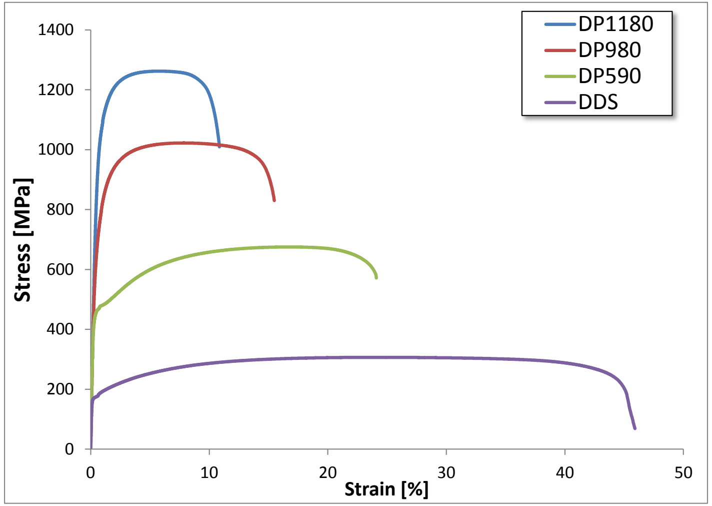






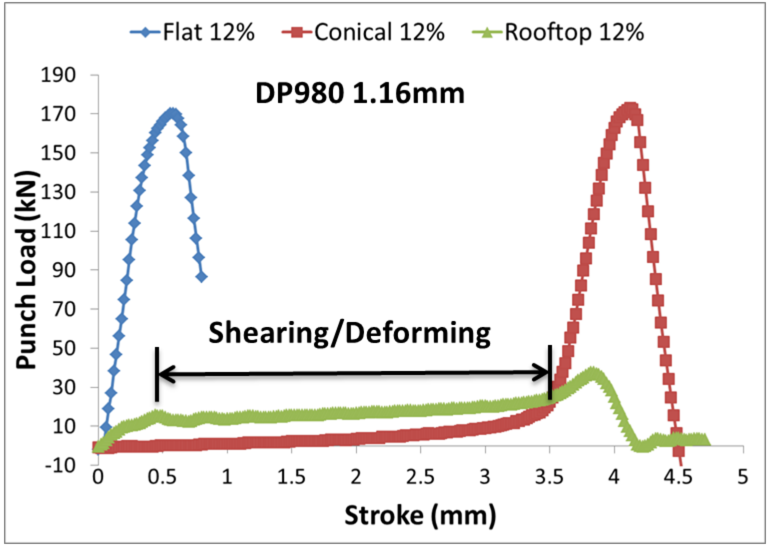
Material Properties

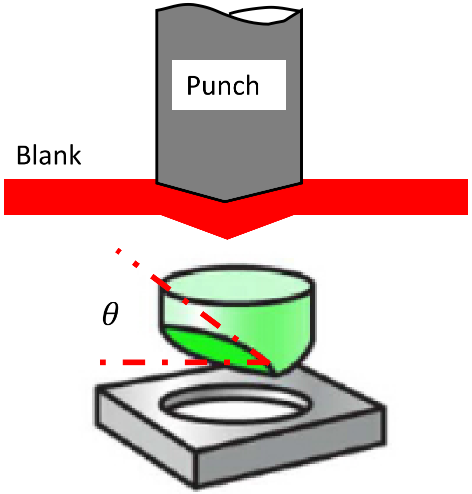
	DP1180 (1.20mm)	DP980 (1.16mm)	DP590 (1.31mm)	DDS (1.38mm)
Yield Strength (MPa)	1002.20	703.52	451.06	162.85
Tensile Strength (MPa)	1269.35	1038.99	675.05	311.23
Uniform Elongation (%)	5.40	7.16	16.45	24.71



Punching Force History

- Conical shaped punch induces large deformation within the cutting area.
- The punch load is quite uniform due to gradual shearing process , similar to scissor cutting for the rooftop punch



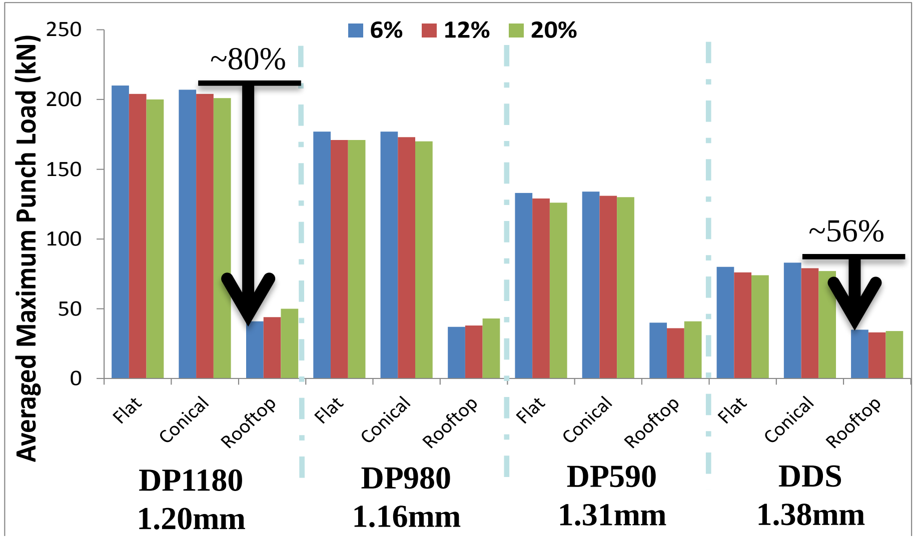


Material deformation induced by conical/rooftop punch

Rooftop Punch Shearing Process

Averaged Maximum Punch Load

- For all cases, the maximum punch load decreases as cutting clearance increases, but the difference is trivial (about 3 to 4%).
- The rooftop punch leads to significant force reduction and it is more effective on AHSS.



Hole Punching Force Coefficient

- The hole punching force coefficient can be calculated as

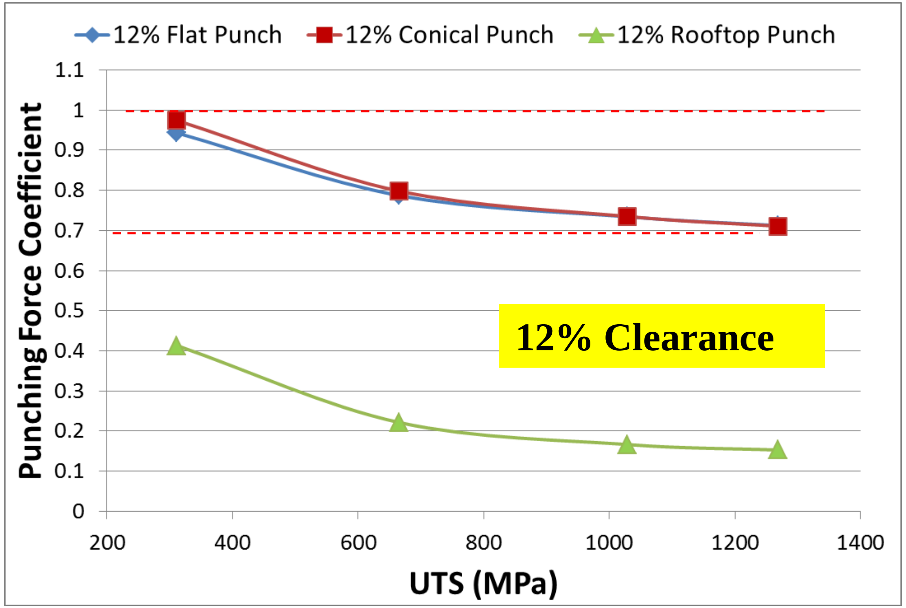
$$K = \frac{P}{\text{UTS} \cdot \pi D \cdot t}$$

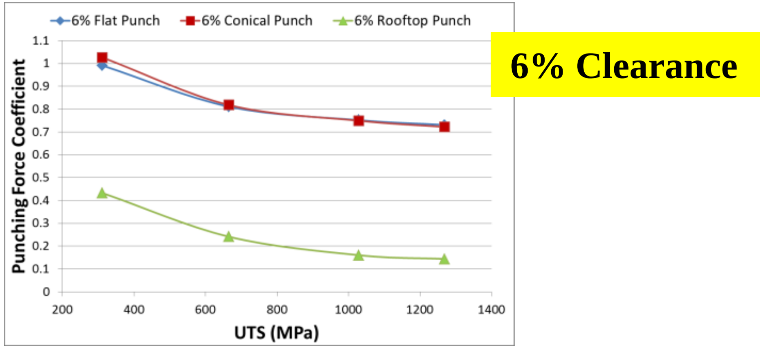
UTS (MPa): ultimate tensile strength
P (N): hole punch force
D (mm): hole diameter
t (mm): material thickness

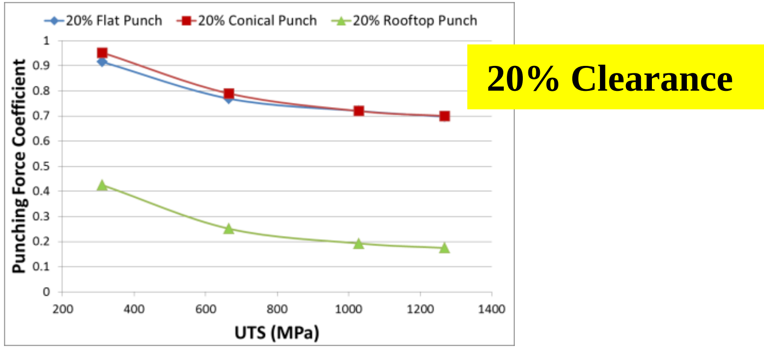
- This definition is similar to the shear strength index. More dependencies are considered during the evaluation.

Hole Punching Force Coefficient

- The hole punching force coefficient is negatively correlated to the material strength.
- Mild steel → 1.0; AHSS: 0.7 ~ 0.8

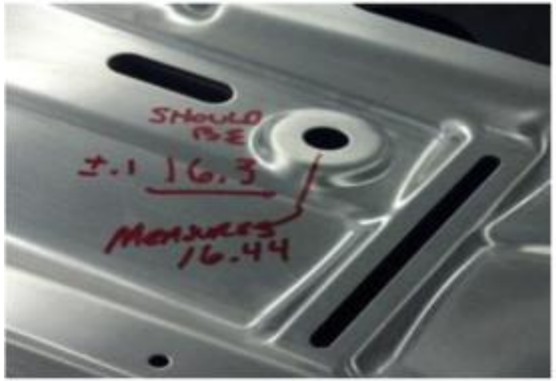




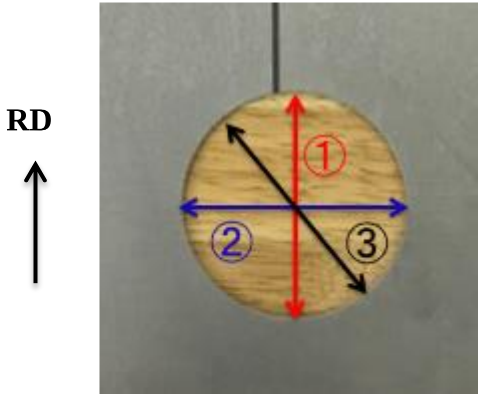


Dimensional Study of Punched Hole

- Dimensional accuracy of punched holes is important in the sheet metal forming.
- Dimensional measurements were repeated for three times for each punch configurations (punch shape, material, and cutting clearance).

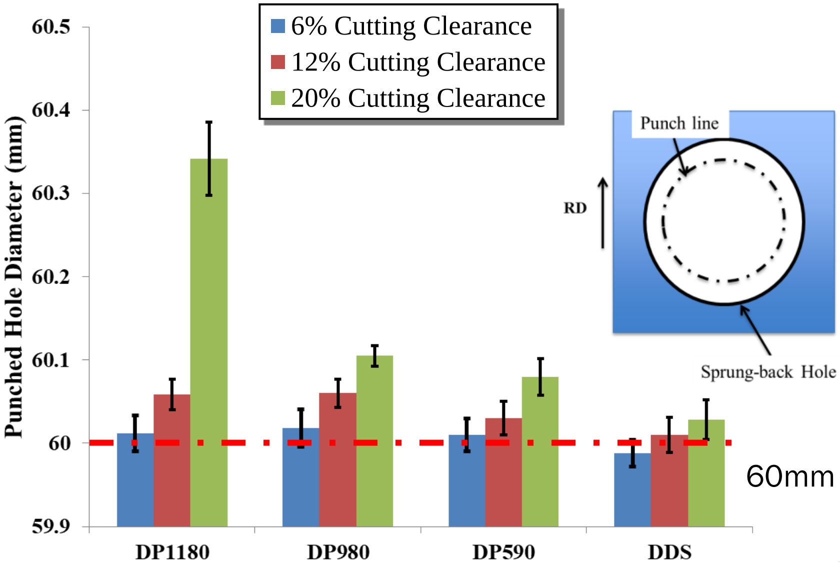


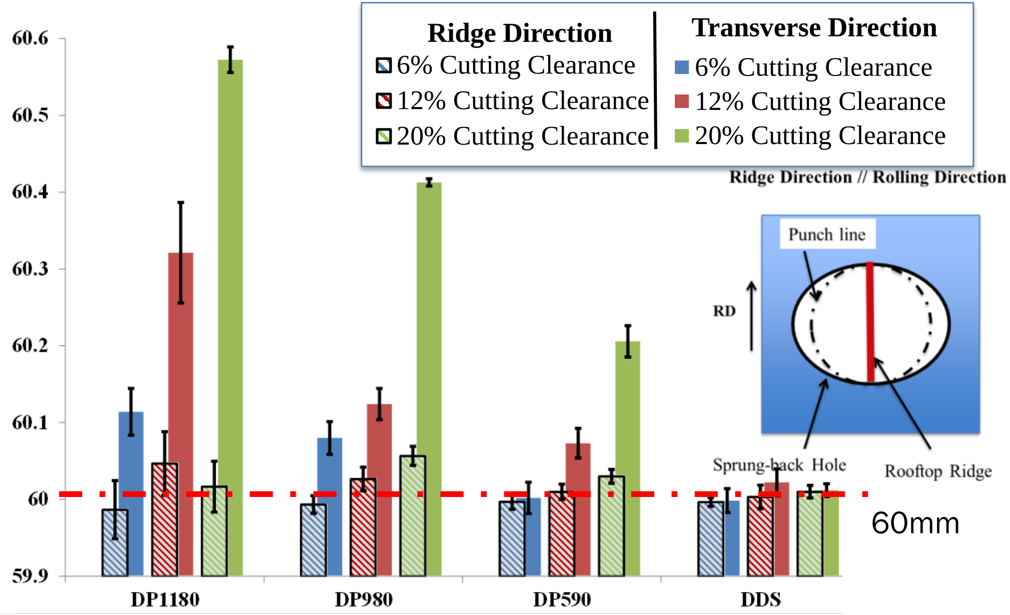
Yang, G. et al, SAE 2016



Hole Discrepancies

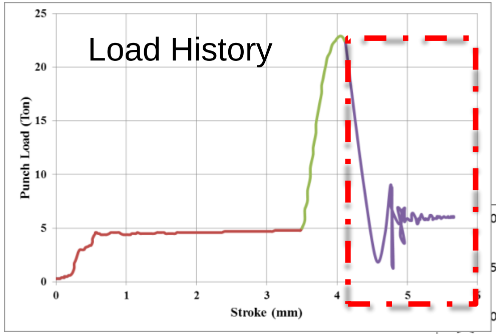
- Conical shape leads to an uniform enlargement for diameter due to the stress release and consequent spring back.
- The holes punched with rooftop shape exhibited oval shape with minor axis along the ridge direction.

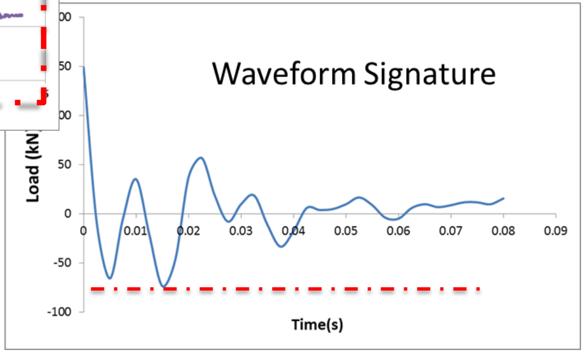


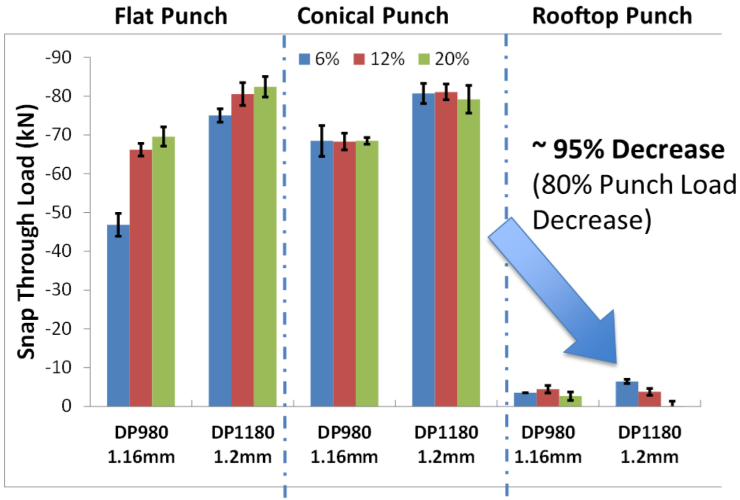


Tool Protections: Snap-through Load

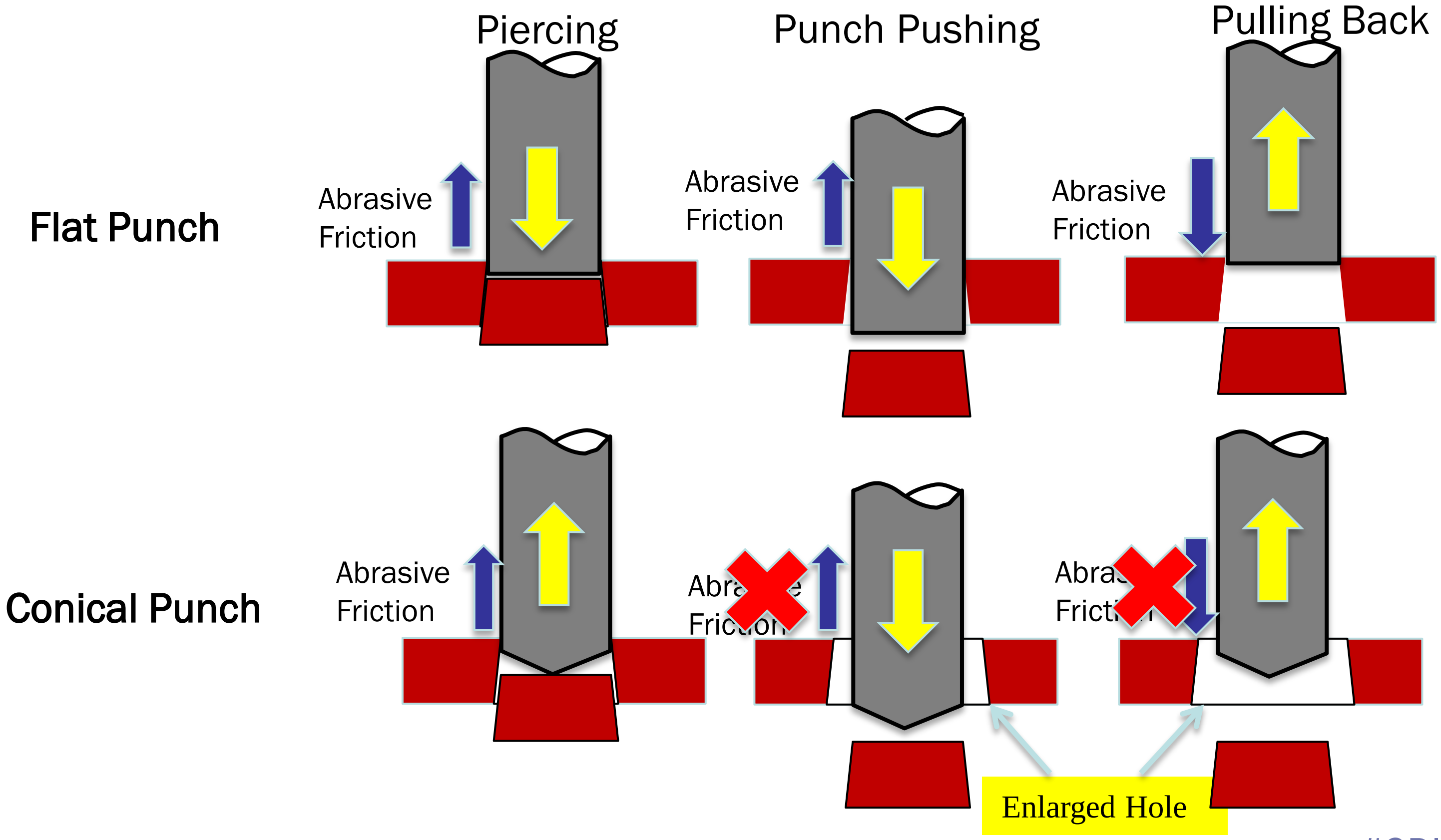
- Snap-through load, i.e. reverse tonnage, leads to severe press machine damage.
- Rooftop punch can provide an effective solution for press machine protection and noise reduction





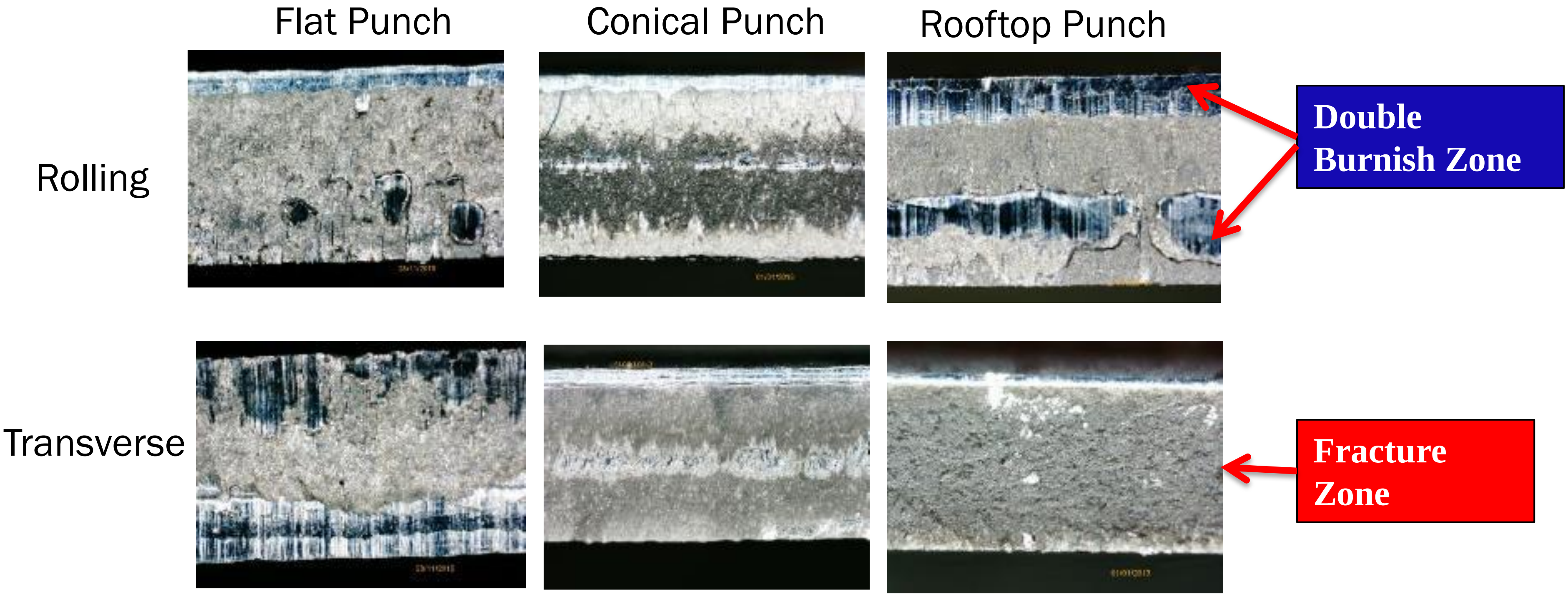


Tool Protection From Enlarged Hole



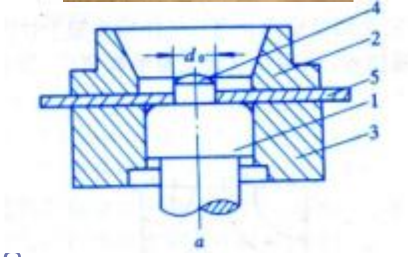
Cutting Edge Quality

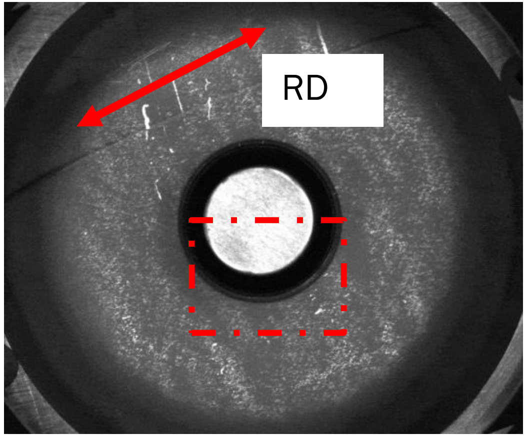
- The cutting surface was examined using optical microscope with 200X magnification.

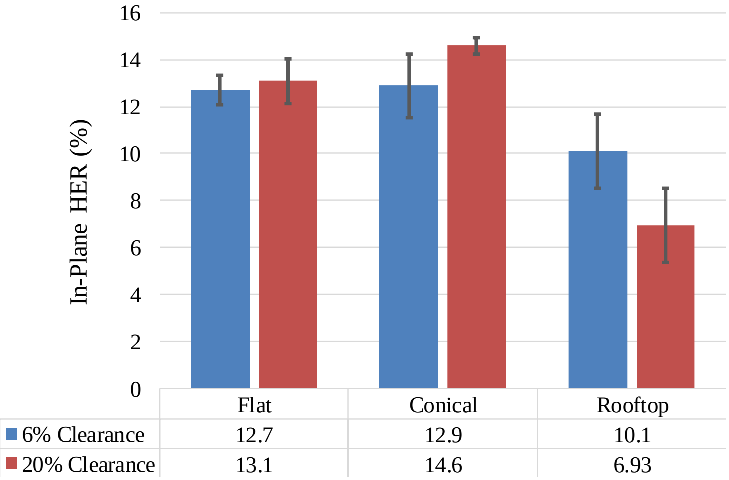


In-plane Hole Expansion Test

- In-plane hole expansion tests were conducted to evaluate the edge damage due to the punch geometry during the punching stage.
- The conical shaped tool can produce a punched hole with higher edge stretchability, while rooftop punch results in the most severe edge damage.

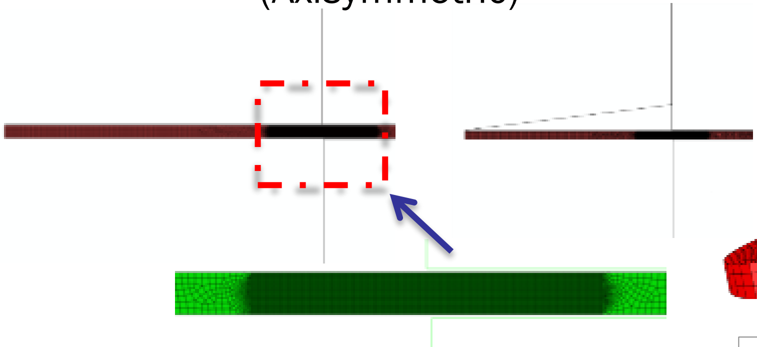




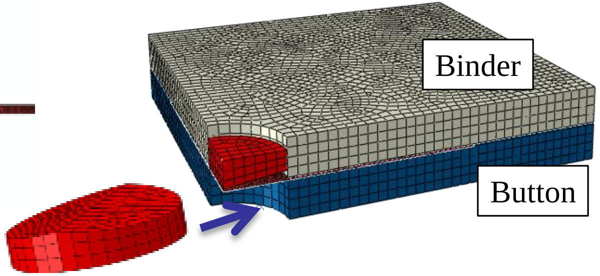


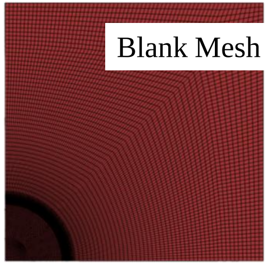
FEA Model

Flat & Conical Punch Model (Axisymmetric)



Rooftop Punch Model (3D Quarter)

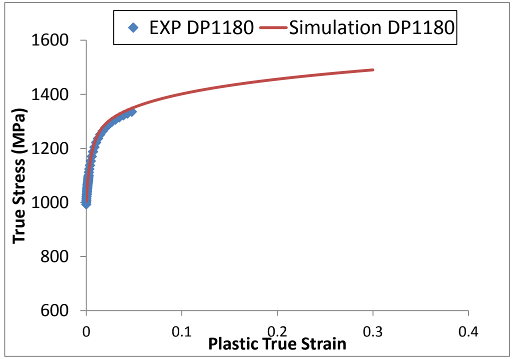


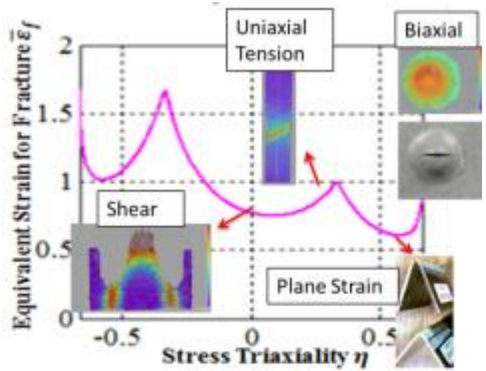


- Mixed-Voce-Swift model

$$\bar{\sigma} = \alpha[K(\bar{\varepsilon}^p + \varepsilon_0)^n] + (1-\alpha)[\sigma_i - (\sigma_i - \sigma_0)\exp(-\bar{\varepsilon}^p/\eta)]$$

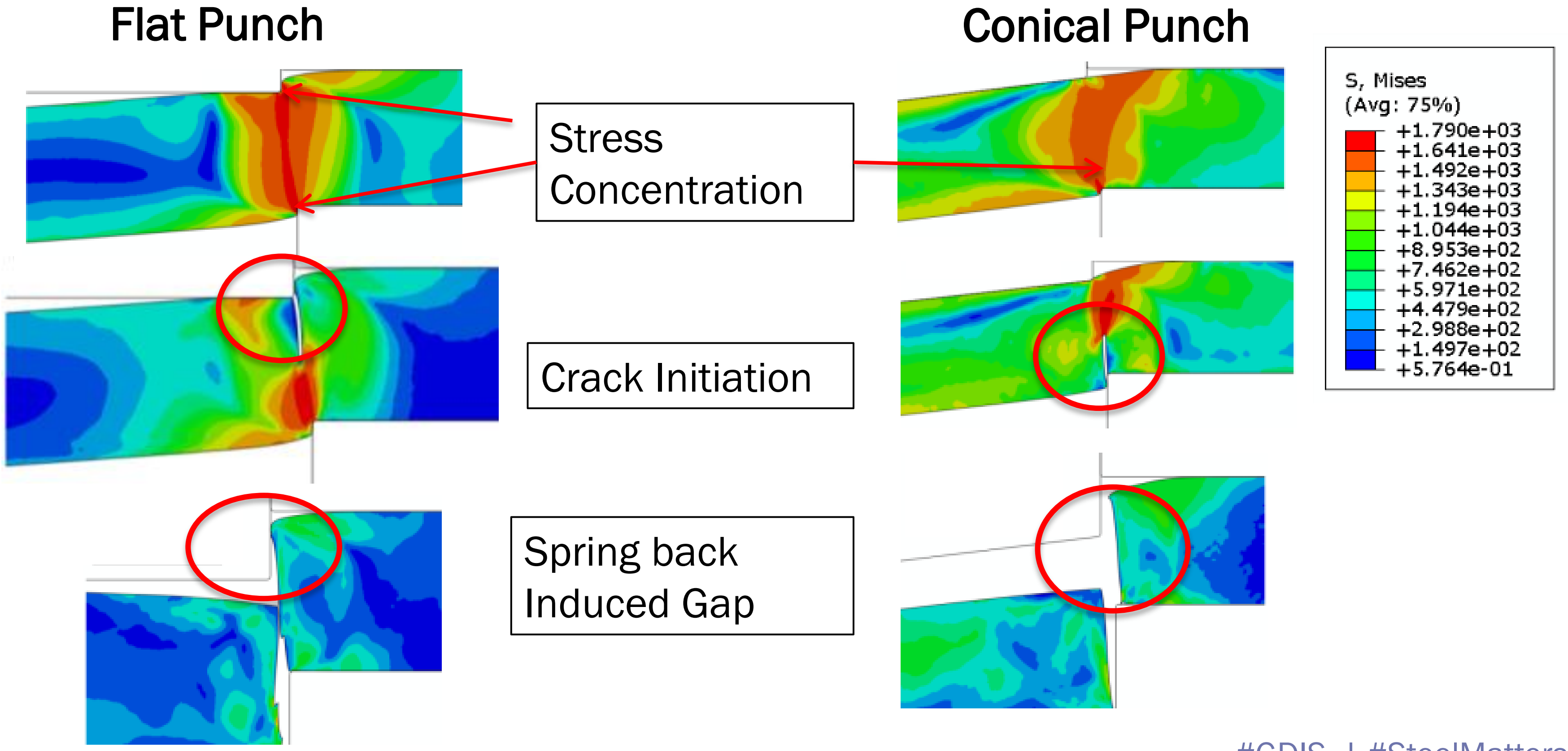
- All-strain Based Modified Mohr-Coulumb (eMMC) Fracture Model



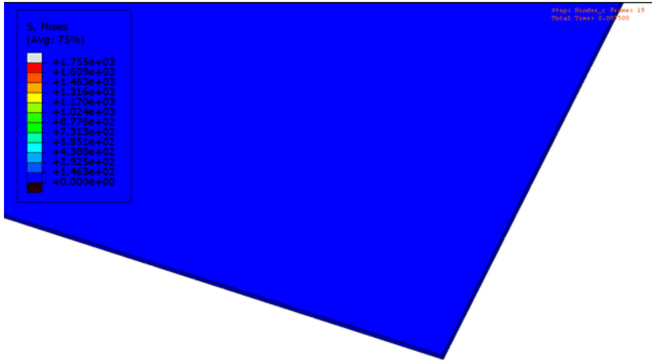


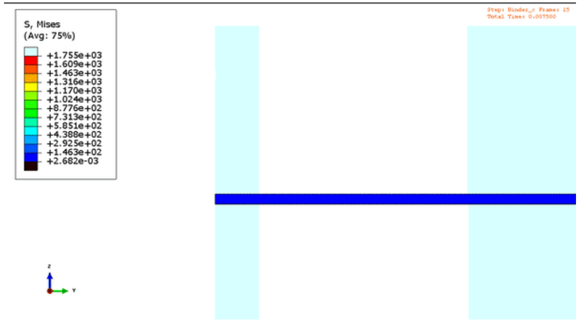
* Test data is provided by WSU through ASP Fracture Project

Punching Process Simulation



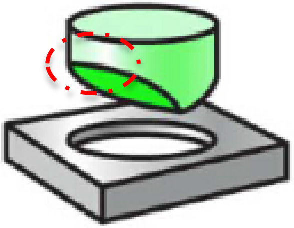
Punching Process Simulation

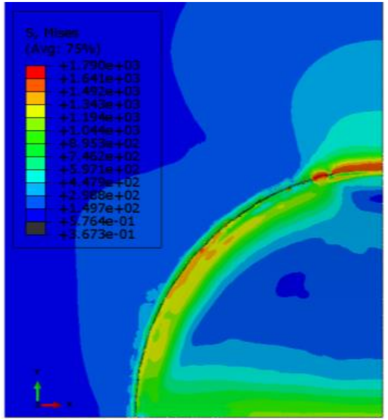


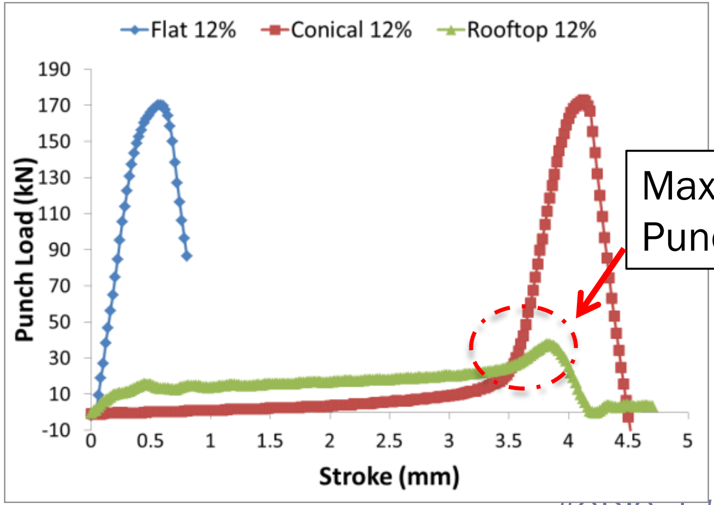


Material deflection before cutting

0 degree shearing angle



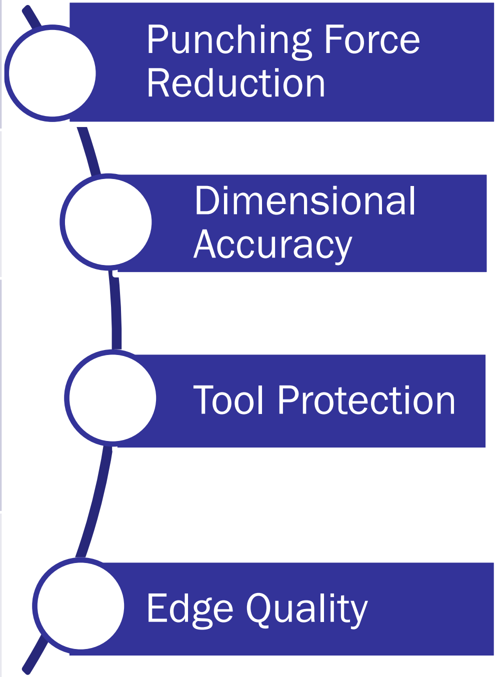




Maximum Punch Load

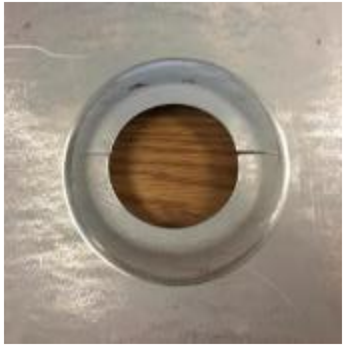
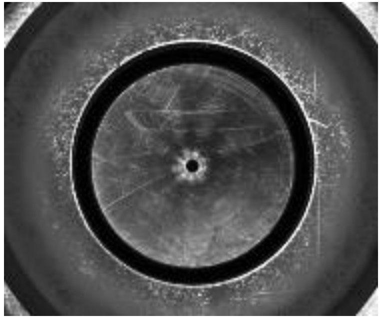
Summary

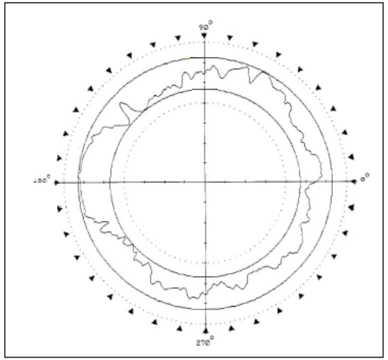
Flat Punch	Conical Punch	Rooftop Punch
No Effect; Force Coefficient:0.7~1	No Effect; Force Coefficient:0.7~1	Significant reduction (56%~80%); Force Coefficient:0.15~0.4
Accurate	Uniformly enlarged diameter; could be compensated	Oval shape with minor axis along the rooftop ridge
Large snap-through load; Multiple abrasive wearing;	Large snap-through load; Reduced abrasive wearing;	Significantly reduced snap-through load;
Inconsistent edge surface condition	Smooth and Consistent Edge Surface	Localized material deformation; Inconsistent edge surface at small clearance



Future Studies

- In-plane hole expansion tests will be continued to study the sheared edge damage mechanism.
- A numerical damage model will be developed to simulate the edge cracking.
- The punch shape and geometry will be optimized to achieve the goals of load reduction and dimensional accuracy.



Roundness Measurement

Thank you!

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