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A Study on the Punch Shape for Improving Tool Life in Shearing AHSS

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Abstract. The adoption of hot rolled AHSS(Advanced High-Strength Steel) has been increased in accordance with the weight reduction of the chassis. The problem of tool life in punching the hole for high-strength steels is more important. Using the high-grade die material is one of the method to improve tool life. Another method for increasing the tool life is reducing the maximum punching load. We investigated the effect of tool shape on reducing the punching load. Conventional, shear-angled and humped tool geometry are considered for punching the flat sheets with 780MPa strength. In flat sheet, the maximum punching load is compared for each case of puch types. Maximum punching load is reduced by 40% of conventional punching process. For investigating the effect of punch shape in a real part, the punching process for the vent hole of the conventional wheel disc is modeled with FEM. The maximum load is efficeintly reduced by using the shear-angled punch.

1. Introduction

In accordance with automobile weight saving needs, it is accelerating to adopt the high-strength steel. The application of high-strength steels with 590MPa or higher tensile strengths in chassis parts is expanding. Due to the high strength of the material, the main problem in forming the chassis is formability especially edge strechability [1]. Research is mainly conducted to improve the edge formability for hot rolled high-strength steel [2-4]. Recently, the issue of the tool life is on the rise as increasing the use of AHSS in chassis parts. The decrease of the life for the punching die causes the increase of maintenance such as an increase in working time, a decrease in productivity and quality problems. Especially chassis parts have more unfavorable conditions for tool wear because of using materials with 2.0mm or more thickness. In addition, the wear and chipping of the die in punching process for shaped-surface occurs more easily than in punching process for flat surface and in drawing process. Figure 1 shows a conventional-type wheel. In the wheel disk, there are many holes such as a hub hole, bolt holes and vent holes. Forming process of wheel disc includes a number of punching processes. Especially the vent hole is located on the curved-shape surface. Therefore the punching tool condition is rapidly deteriorated, for example by chipping or abrasion. In addition, the abrasion of tool is inevitably accelerated because the punching load for higher-strength steels increases. One of the methods increasing the tool life is using the high grade die material. It is also expected that the tool life can be extended by reducing the shearing load by changing the tool. In this paper, four types of punch with the same die material and the different shape are tested for punching the hole on a flat sheet with 780MPa strength. FEM analysis is carried out for investigating the effect of tool shape on punching the vent hole in the wheel disk.

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Figure 1. Conventional-typed Wheel.

2. Shearing Punch and Punching Load

Shear load in punching is proportional to tensile strength, shear length and material thickness as shown in Equation (1). Where P is the shear load (kgf), t is the thickness of the workpiece (mm), L is the shear length (mm), S is the shear resistance (kgf / mm^2). Generally the shear resistance is two-thirds of tensile strength.

$$P = L \times t \times S \tag{1}$$

The shear load can be reduced by changing the tool shape in the punching process. The punching test was performed to evaluate the shear load on the five types of punch shown in Figure 2. (a) The conventional type of punching tools. (b) Humped punch[5] has the effect of improving the edge stretchability by lowering edge hardening by inducing rapid fracture at relatively low deformation. Also, it is expected that the concentrated load at the corner of the tool can be alleviated due to the hump. (c) The shear load can be reduced by sequentially shearing along the circumferential direction. (d) A hybrid-typed punch combined with sheared angle and a hump. In the case of a punch with a shear angle, although the effect of reducing the load is large, there is a risk of premature failure due to the concentrated load at the end of the punch. The hybrid type punch of (d) has the effect of compensating the weakness of the shear angle punch at the end humped. Table 1 shows the maximum shear load for four different materials in punching the PO780 Grade. Punching diameter is 20mm and the material thickness is 3.2mm. The punching load of conventional punch is about 120kN. The load reduction of the humped punch is hardly shown. For shear angle punch, all of materials A to D show large load reduction about 50%. Hybrid type punch also reduces the maximum punch load up to 45% in material D. Based on the results in the Table 1, it is expected that the effect of reducing the maximum punching load improves the life of the punch.

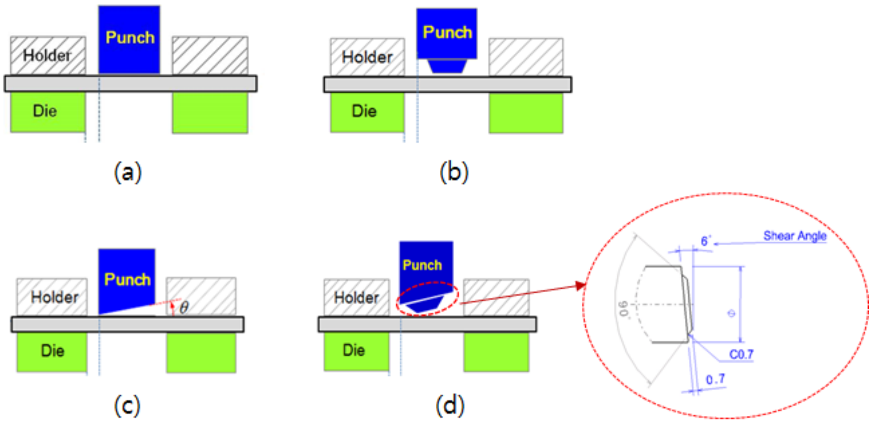


Figure 2. Shearing punch shape for maximum shear load test,
(a) Conventional, (b) Humped, (c) Shear angle 6°, (d) Hybrid type.

Table 1. Maximum shearing load(Kn) of PO780 Grade (ø 20mm, Clearance 12%t).

Punch Type	FB780	DP780	HB780
Conventional	118	118	128
Humped	116	112	128
Shear angle 6°	56	51	76
Hybrid	85	74	97

3. Materials Properties and FEM Model

The model for shear analysis is shown in Figure 3. The model used for the analysis is the 1/16 symmetrical model of a conventional wheel disc with 16 vent holes. The configurations of the punch, die and holder are applied in the same manner as the actual mass production process. The different shapes of the punch applied to the shear analysis is shown in Figure 4. The product-faced punch has the same punch bottom surface as the product surface of the wheel disc. The punch (c) has the hump at the bottom of the Product-faced punch. The shear angle punch has the shear angle, and hybrid punch is a shear angled punch with hump. Generally, the shear angle has an effect on reducing the noise and the load in the punching process. In case that a shear angle is applied to a circular shear punch, such as a wheel disc part, the load may be concentrated on the first contact region with the material and the premature failure may occur. The humped punch has an effect of reducing the hardening of sheared edge by promoting the fracture at a relatively low deformation [4]. The humped punch enhances the edge-stretchability but does not reduce the shear load. We design the punch shape based on load reduction data in the flat sheet materials as shown in Table 1. The results in Table 1 are obtained under the ideal condition, and the most effective data is obtained. It is necessary to verify how much load can be actually reduced due to the shape of vent holes part in mass production wheel disc.

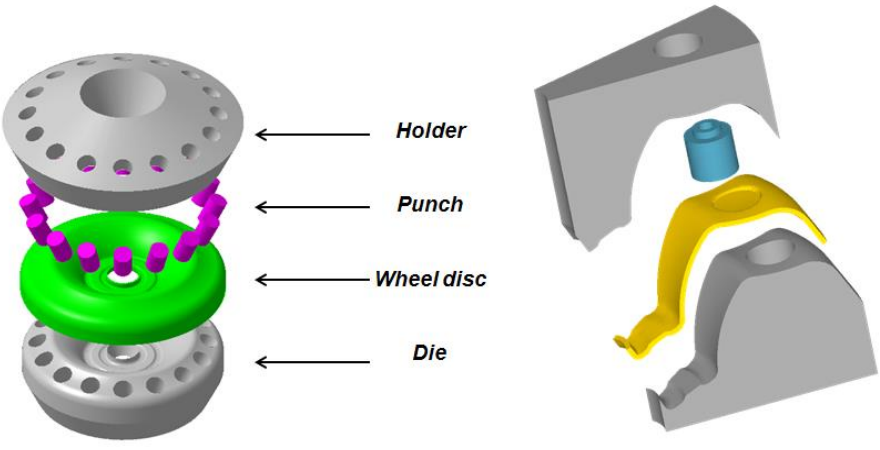


Figure 3. Analysis model of vent hole punching for wheel disc and punching tools.

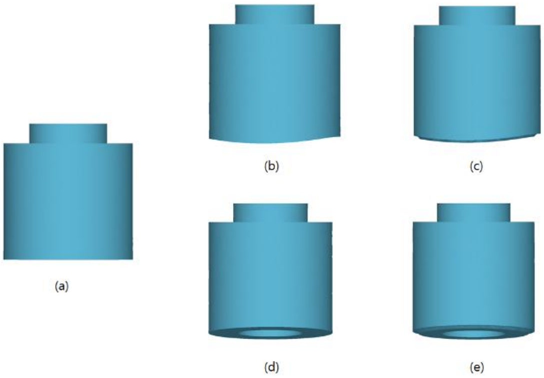


Figure 4. Shearing punch shape for shearing analysis, (a) Conventional punch, (b) Product-faced punch, (c) Product-face humped punch, (d) Shear angle punch, (e) Hybrid punch.

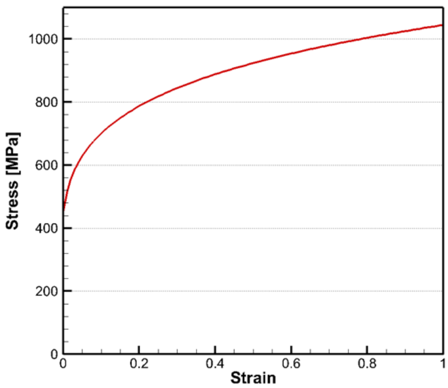
The material of the wheel disk is PO590DP (Dual Phase) steel with 3.6mm thickness. Mechanical properties and analytical properties are shown in Tables 2 and 3. The material of the punching tool is SKD11 which is commonly used in general mass production tool steel, as shown in Table 4. Shear analysis is performed through DEFORM 3D Version 11.0.

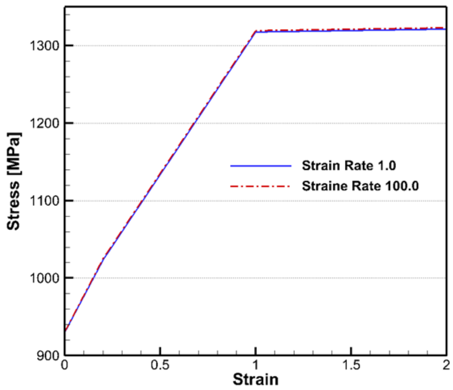
Table 2. Mechanical property of PO 590 grade.

Material	Thickness [mm]	YS [MPa]	TS [MPa]	EL [%]	n
590DP	3.2	455	646	26	0.17

Table 3. Swift equation fitting property of PO590 grade.

Flow Curve	**K [MPa]**	e_0	**n**
Swift (Krupkowsky)	1043	0.00998	0.180





(a) (b)

Figure 5. Plastic stress-strain curve of (a) PO 590 grade and (b) Tool Material.

Table 4. Material property of a tool material (JIS-SKD11, AISI-D2, COLD).

	strain	0.0	0.2	1	2
strain rate 1	stress	930	1023.12	1317.24	1321
strain rate 100		931	1025.12	1319.24	1323

4. Results of Punching Analysis

Figures 6 and 7 show the result of shear analysis using conventional punch for the vent hole punching of wheel disc part. Figure 6 shows the strain distribution of the workpiece when the punch undergoes the maximum load. Figure 7 shows the stress distribution of the punch and shows the nonhomogeneous contact between the punch and the part. Figure 8 shows the stress distribution of the punch according to the punching stroke in the conventional punch. The stress distribution of the bottom of punches is not uniform along the circumferential direction in the initial punching stroke. The stress is uniformly distributed after the 2.1 mm punch stroke to the entire circumferential direction. This is because of the difference between the surface of the workpiece and the bottom surface of punch. Because of this difference, shear occurs sequentially, and it has the effect of having a shear angle as shown in (c) of Figure 2, even though it is a conventional flat punch. Figure 10 shows a graph of the shear load of a conventional punch. The maximum load is about 228 kN and fracture occurs at the maximum load point.

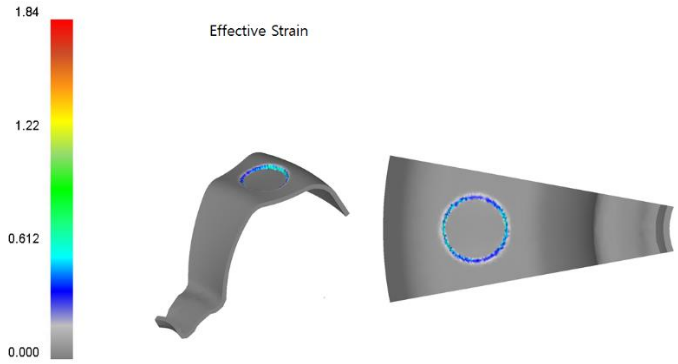


Figure 6. Strain distribution of part shearing process applied conventional punch, PO590DP.

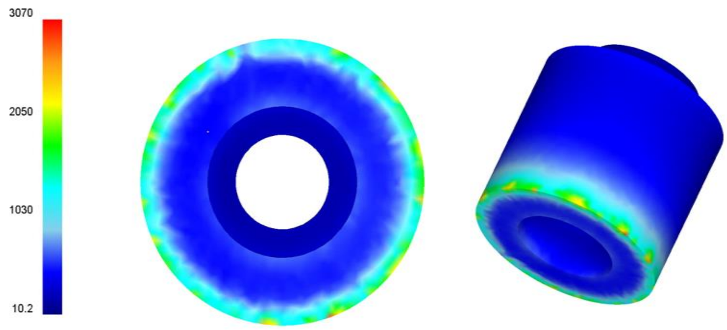


Figure 7. Stress distribution of conventional punch tool at maximum punch load.

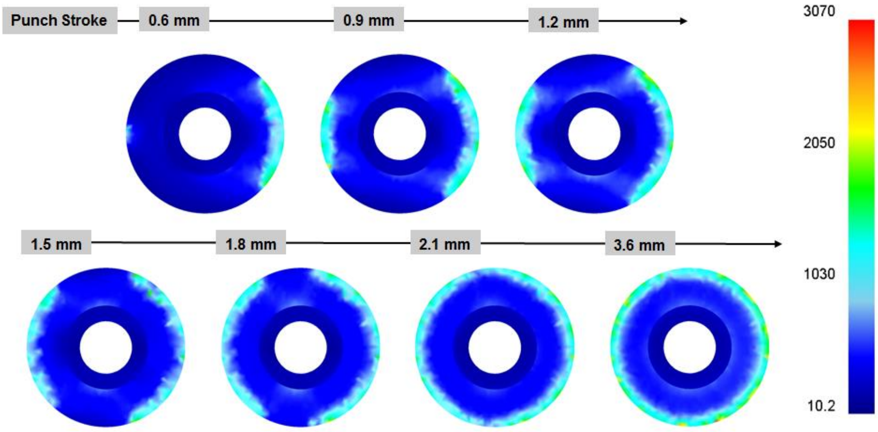


Figure 8. Stress distribution of conventional punch tool according to the punch stroke.

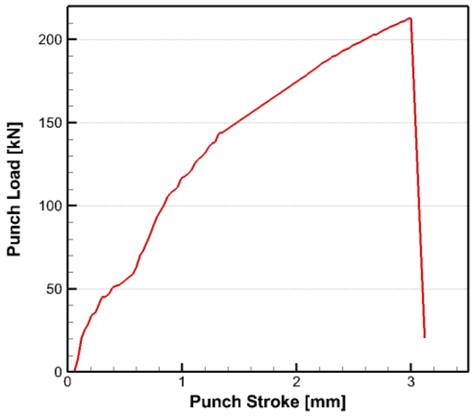


Figure 9. Punching stroke-load curve of conventional punch.

Table 5. Maximum shear load according to punch shape.

Punch type	Conventional	Part-faced	Part-faced Humped	Shear-angled	Hybrid
Max. force [kN]	228	254	230	186	180

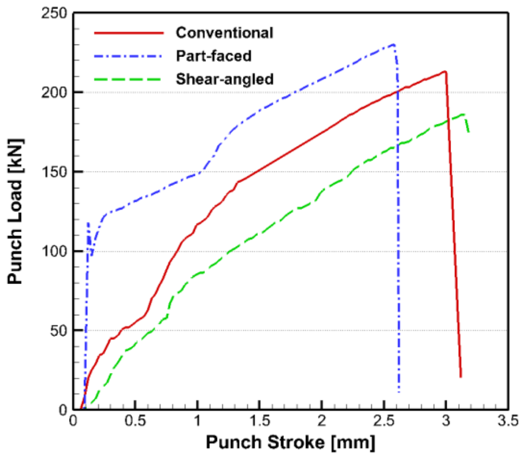


Figure 10. Punching stroke-load curve for three types of punches.

Table 5 shows the maximum load at the vent hole shear according to the 5 types of punch shape. The maximum shear load of the punches based on the shape of part faced type are higher than conventional punch load. On the other hand, in the two punches with shear angles, the maximum load was about 20% lower than conventional punches. Hybrid punches are most effective for reducing loads.

Figure 10 shows the load curve according to the punch stroke in the shear analysis of conventional punches, part-faced punches, and shear-angled punches. As mentioned earlier, part-faced punch shows the highest shear load in the shortest punch stroke. Shear-angled punch has the lowest shear load under all three conditions and the punch stroke increases about 0.5 mm compared to conventional punch. As can be seen from the results of Table 1, the largest shear load is generated in the case where the surface shape of workpiece and the punch coincide with each other. And shear progresses simultaneously in the circumferential direction. In addition, hybrid punch is given to obtain the lowest shear load when sequential shearing progresses. As shown in this paper, in case of the shape of the workpiece and the bottom surface shape of punch do not match, the maximum shear load may be relatively low, but the load is concentrated at the end of the punch.

In Figure 10, there is a difference in the punch stroke depending on the shape of the punch. This is because the difference of the surface shape between workpiece and the punch. In the case of a part-faced punch, there is no gap between the material to be processed and the punch, and the shear-angled punch has a longer punch stroke due to the sloped degree. In actual production, it has a sufficient punching stroke for reasons such as scrap discharge and stable quality assurance. Therefore, the difference in punching distance within a few millimeters will not affect the productivity.

5. Conclusions

The following conclusions were obtained through the analytical results of the punch shape which can reduce the load in the press shear.

(1) The shear load is highest in the shape where the workpiece and the bottom surface of the punch coincide.

(2) When shear punch with shear angle is applied, lower load than conventional punch can be obtained.

(3) When sequential shearing occurs, a high concentrated load occurs at the initial contact area.

(4) The hump of the punch bottom prevents the concentration of the load.

(5) It is possible to reduce the maximum shearing load by applying the shear angle and hump of the punch in the shearing process, thereby improving the life of the shearing tool.

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