Flanging using step die for improving fatigue strength of punched high strength steel sheet

Purwo Kadarno*, Ken-ichiro Mori, Yohei Abe, Tatsuro Abe

Abstract

The fatigue strength of a punched high strength steel sheet having 590 MPa in nominal tensile strength was improved by thickening a hole edge by means of flanging using a step die and round corner punch. The sheared edge was thickened by flanging, and then was compressed with the corner step of the die. The quality of the sheared edge for the thickened punched sheet was improved by ironing with the round corner of the punch during the thickening process. It was found that the fatigue strength of the punched sheet with thickening was larger than that without thickening because of the increases in the thickness, surface quality and hardness in the sheared edge.

Keywords: Punching; Thickening; Hole edge; High strength steel sheet; Fatigue strength

1. Introduction

The reduction in weight of automobiles is effective in improving the fuel efficiency, and forming processes of lightweight materials have been actively developed (Kleiner et al., 2003). The application of high strength steel sheets to body-in-white parts is the most attractive among other lightweight materials due to the high specific strength and cost competitiveness. In stamping operations of high strength steel sheets, large springback, small formability, short tool life, etc. are problematic due to high strength and low ductility (Mori et al., 2007).

* Corresponding author. Tel.: +81 532 44 5213; fax: +81 532 44 6690.
E-mail address: kadarno@plast.me.tut.ac.jp
Nomenclature

\( h \) step height of the die  
\( s \) punch stroke  
\( x \) distance of edge from rollover

Body-in-white parts are generally punched to make many holes for joining, paint removing, attachment, reduction in weight, etc. In punching of high strength steel sheets, tools tend to wear and chip due to large punching load, and thus the tool life is short (Eriksson and Olsson, 2011). In addition, the quality of the sheared edge deteriorates since the onset of cracks in the shearing is early due to the small ductility.

In high strength steel sheets, the static strength of formed products is almost proportional with the strength of the sheet, whereas the increase in fatigue strength becomes gradually small (Murakami et al., 1989). In addition, onset and progress of fatigue cracks of the punched high strength steel sheets are accelerated by the concentration of stress around the holes, particularly for rough fracture surface and sharp burr of the sheared edge (Thomas et al., 2011). Therefore, the improvement of the quality of the sheared edge of punched sheets is useful for increasing the fatigue life. Mori et al. (2013) have improved a sheared edge of ultra-high strength steel sheets in slight clearance punching with a punch having a small round edge. Matsuno et al. (2010) have employed a punch having a round corner and an inclined bottom for punching of thick high strength steel sheets and examined the fatigue properties of the punched sheets. Although the fatigue strength is improved by the quality of the sheared edge, the improvement is not enough to extend the applicable range of high strength steel sheets.

The concentration of stress around the punched hole is relieved by increasing the thickness around the hole edge by means of flanging, and thus the fatigue strength may be improved. Kadarno et al. (2012) have examined the effect of the thickening of the hole edge by flanging on the fatigue strength of punched high strength steel sheet. In the hole flanging operations, a sharp edge is usually formed in the thickened edge, thus the strength deteriorates.

In the present study, the hole edge of a punched high strength steel sheet was thickened by flanging using a round corner punch with a step die to improve fatigue strength of the punched sheet. The formation of sharp edge in the thickened edge was prevented by the corner step of the die. The shapes of the tools were designed for the thickening of the hole edge by finite element simulation. The quality of the sheared edge for the thickening was compared with that without the thickening. The effect of the thickening on the strength of the punched sheets was evaluated.

2. Thickening of hole edge by hole flanging

To improve the fatigue strength of a punched high strength steel sheet, the edge of the hole is thickened by a hole flanging operation as shown in Fig. 1. In this process, the sheet is punched for smaller hole diameter in the former stage, then the thickness around the hole edge is increased by forcing the edge of the punched hole into a die. In the thickening process using a straight die, a sharp edge is formed in the thickened edge, thus the stress is concentrated and the strength of the punched sheets deteriorates. To eliminate the sharp edge in the thickened edge, a step die is employed. By using the step die, the formation of sharp edge is prevented and the thickened edge is compressed by the corner step of the die, thus the strength of the punched sheet is improved.

The dimensions of the tools used in the thickening of the hole edge of the punched high strength steel sheet are shown in Fig. 2, where \( h \) is the step height of the die. A round corner punch having radius of 6 mm was used in the experiment. A straight die having no corner step with 11.4 mm in diameter was also employed as a comparison.

The high strength steel sheet JSC590 having 1.4 mm in thickness was used in the experiment. The sheet was punched with a flat punch having 9 mm in diameter before the thickening, where the ratio of the clearance to the sheet thickness for punching process was 20%. The mechanical properties of the high strength steel sheet JSC590 measured from the tensile test are given in Table 1.

Finite element simulation of the thickening of hole edge using the commercial software ABAQUS was performed under axi-symmetric deformation. The die, sheet holder and punch were assumed to be rigid and the cross-section of the sheet was divided into quadrilateral ring elements. The coefficient of friction at the interface
between the tool and sheet was assumed to be 0.1. The cross-sectional shape of the punched sheet obtained from the experiment was used as an input for the simulation of thickening process. The work-hardening by the punching was neglected in the simulation.

Fig. 1. Thickening of hole edge of high strength steel sheet by hole flanging, (a) punching stage. (b) Thickening of hole edge using straight die and (c) step die.

Fig. 2. Dimensions of tools used in thickening hole edge of high strength steel sheet.

Table 1. Mechanical properties of high strength steel sheet JSC590.

<table>
<thead>
<tr>
<th>Property</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Flow stress (MPa)</td>
<td>979$e^{0.16}$</td>
</tr>
<tr>
<td>Tensile strength (MPa)</td>
<td>632</td>
</tr>
<tr>
<td>Elongation (%)</td>
<td>24</td>
</tr>
<tr>
<td>Reduction of area (%)</td>
<td>55</td>
</tr>
</tbody>
</table>

3. Results of thickening of hole edge

3.1. Deformed shaped

To determine the step height of the die, the calculation was performed for the different step height of the die. The shapes of the hole edge after the thickening process obtained from the calculation for different step height of the die $h$ are shown in Fig. 3. The burr is formed for $h = 0.5$ mm due to the excessive filling of the die, whereas the
sharp edge in the thickened edge is formed for \( h = 0.7 \) mm due to the under filling of the die. The die height is optimized for \( h = 0.6 \) mm, thus this die was fixed for the following experiments.

![Fig. 3. Shapes of hole edge after thickening process obtained from calculation for (a) \( h = 0.5 \) mm, (b) \( h = 0.6 \) mm and (c) \( h = 0.7 \) mm.](image)

The deformation behaviours of the sheet during the thickening of hole edge process obtained from the experiment for \( h = 0.6 \) mm, the straight and step die are shown in Fig. 4, where \( s \) is the punch stroke. Although the fracture surface and sharp edge are appeared on the thickened edge for the straight die, the formation of sharp edge and fracture portion are prevented by the corner step of the die for the step die.

![Fig. 4. Deformation behaviours of sheet during thickening of hole edge process obtained from experiment for \( h = 0.6 \) mm, (a) straight and (b) step die.](image)

3.2. Quality of sheared edge

The surface and cross-section of the sheared edge with and without thickening for straight and step die are compared with that without thickening using a flat punch having a diameter of 10 mm in Fig. 5, where the ratio of clearance between the punch and die to the sheet thickness for the flat punch was 20%. Although the area of the rough fracture surface for the punched sheet without the thickening is large, the rough fracture surface is considerably reduced for the thickening and almost disappears for the step die.

![Fig. 5. Comparison of (a) straight and (b) step die with and without thickening.](image)

The distributions of the surface roughness of the sheared edge in the thickness direction with and without the thickening for \( h = 0.6 \) mm are shown in Fig. 6(a). The surface roughness was measured at intervals of 0.1 mm in the thickness direction. The surface roughness of the thickened sheared edge for the step die is considerably smaller than that without thickening and the straight die due to the elimination of fracture surface.

The distributions of Vickers hardness in the thickness direction around the sheared edge with and without thickening for \( h = 0.6 \) mm are shown in Fig. 6(b). The hardness was measured in the cross-section at 0.2 mm from
the sheared edge. The hardness with thickening is higher than that without thickening due to ironing with the round corner of the punch during the thickening stage. Moreover, the hardness for the step die is higher than that for straight die due to the compression of the thickened edge with the corner step of the die.

Fig. 5. Surface and cross-section of sheared edge of punched sheet for $h = 0.6$ mm (a) no thickening, (b) thickening using straight die and (c) step die.

![Fig. 5](image)

Fig. 6. Distributions of (a) surface roughness and (b) Vickers hardness of sheared edge in thickness direction with and without thickening for $h = 0.6$ mm.

4. Fatigue strength of punched sheet

The bending and tensile fatigue tests of the punched sheets with the thickened hole edge were performed. The frequencies for the alternative bending and repeated tensile fatigue tests were set at 25 and 50 Hz, respectively. The fatigue tests were ended when the sheet was ruptured.

The comparisons of the number of cycles to failure between the punched sheets with and without the thickening of the hole edge for $h = 0.6$ mm, bending and tensile fatigue tests are shown in Fig. 7. The bending moment and maximum load for the bending and tensile fatigue tests were set for 2.74 N·m and 9.92 kN, respectively. The fatigue strength of the punched sheets with thickening is considerably higher than that without thickening. The fatigue strength for the punched sheet for the thickened hole edge is improved by the thickness increase, the smooth sheared surface and the harder the surface around the hole edge. The fatigue strength of the punched sheet
for the step die was higher than that for the straight die due to the elimination of the rough fracture surface in the sheared edge and the compression of the thickened edge by the corner step of the die.

![Fig. 7. Number of cycles to failure between the punched sheets with and without thickening of the hole edge for $h=0.6$ mm (a) bending and (b) tensile fatigue tests.](image)

5. Conclusions

The hole edge of the punched high strength steel sheets was thickened by a hole flanging process using a round corner punch and a step die to improve the fatigue strength of the punched sheets. The results are summarized as follows:

1. The formation of sharp edge in the thickened edge was prevented by the corner step of the die, moreover the thickened edge was compressed.

2. The surface quality of the sheared edge for the punched sheet with thickening using step die was improved due to ironing with the round corner of the punch, and compression of the thickened edge with the corner step of the die during thickening process.

3. The fatigue strength for the punched sheet with thickening was improved by the thickness increase, the smooth sheared surface and the harder the surface around the hole edge.

References


