Improvement of formability of high strength steel sheets in shrink flanging

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Abstract. In the shrinkage flanging, the wrinkling tends to occur due to compressive stress. The wrinkling will cause a difficulty in assembling parts, and severe wrinkling may lead to rupture of parts. The shrinkage flange of the ultra-high strength steel sheets not only defects the product by the occurrence of the wrinkling but also causes seizure and wear of the dies and shortens the life of dies. In the present study, a shape of a punch having gradual contact was optimized in order to prevent the wrinkling in shrinkage flanging of ultra-high strength steel sheets. The sheet was gradually bent from the corner of the sheet to reduce the compressive stress. The wrinkling in the shrink flanging of the ultra-high strength steel sheets was prevented by the punch having gradual contact. It was found that the punch having gradual contact is effective in preventing the occurrence of wrinkling in the shrinkage flanging.

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 [1]. Although the application of aluminium and titanium alloy sheets are attractive lightweight materials for reduction of the automobile weight [2], the high cost and small formability are crucial problems [3], thus the industry still has a great interest in steel sheets. A hot bending using resistance heating was used to form the titanium alloy sheet [4]. By having the high specific strength and cost competitiveness, the high strength steel sheets are the most attractive for body-in-white parts. The strength of high tensile strength steel sheets remarkably increases and ultra-high tensile strength steel sheets more than 1 GPa have been developed. In stamping operations of high strength steel sheets, large springback, small formability, short tool life, etc. are problems, particularly ultra-high strength steel sheets...
having a tensile strength above 1 GPa [5].

Since most of the high strength steel sheets are made for body-in-white parts, the bending is a more preferable process for ultra-high strength steel sheets [6]. However, the bending becomes difficult due to the ultra-high strength steel sheets have large strength and small ductility. In addition, instead of bending the flange in a straight line, the parts are bend in convex (shrink) and concave (stretch) shape which caused the product to wrinkle due to the compressive stress and crack due to the excessive tensile stress, respectively [7]. Although the results may be predicted using FEA, the calculated results by the finite element simulation are reaching the limit of the accuracy [8] due some approximations and assumptions. Thus, the design of stamping processes of high strength steel sheets becomes difficult.

In the shrinkage flanging, the wrinkling tends to occur due to compressive stress [9]. The wrinkling becomes difficult to assemble parts, and severe wrinkling brings about rapture of parts [10]. The shrinkage flange of the ultra-high strength steel sheets not only defect the product by the occurrence of the wrinkling but also caused the seizure and wear of the dies and shorten the life of parts [11]. Since the formed part with wrinkling defect requires to be trimmed at later stage using the trim dies, it will also shorten the life of the trim dies. Although using the thin high strength steel sheet give advantages in manufacturing the lightweight car however it is less stiff and tendency to become wrinkle is high.

In the present study, a shape of a punch having gradual contact was optimized in order to prevent the wrinkling in shrinkage flanging of ultra-high strength steel sheets. The sheet was gradually bent from the corner of the sheet to reduce the compressive stress.

2. Procedure of shrink flanging

An ultra-high strength steel sheet JSC1180YN with a length, width and thickness of 140, 190 and 1.22 mm respectively was used. The mechanical properties of the sheet are given in the Table 1.

| Description      | Values     |
|------------------|------------|
| Thickness        | 1.22 mm    |
| Tensile strength | 1215 MPa   |
| Elongation       | 10.8%      |
| Flow stress      | $\sigma = 1183 \epsilon_{0.1}$ MPa |

The dimensions of the tools used in the shrink flanging with a punch having gradual contact are shown in Figure 1. The punch having gradual contact has a projection in the central region for gradually bending the sheet from the corner. The experimental conditions are given in Table 2, where $\alpha$ is the projection angle of the punch shown in Figure 1 and $C$ is the clearance ratio between the punch and die.
Table 2 Experimental conditions of shrink flanging with punch having gradual contact

| Condition                  | Value           |
|---------------------------|-----------------|
| Projection angle of punch | $\alpha = 0 - 30^\circ$ |
| Clearance ratio           | $C = 100 - 120\%$ |
| Flange length             | $L = 7 - 12\ mm$ |
| Punch velocity            | 80 mm/s         |

3. Optimization of projection angle of punch
To optimize the projection angle of the punch, the finite element simulation using the commercial software LS-DYNA was performed. In the calculation, the coefficient of friction between the punch and sheet was assumed to be 0.1. The relationship between the calculated wrinkle height and punch stroke for the clearance ratio $C=110\%$ and the bent flange length $L=10\ mm$ is shown in Figure 2. The wrinkling occurs in the vicinity of the corner of the sheet, and the wrinkle is very large for the flat punch of $\alpha=0^\circ$. When the wrinkle height is larger than 0.075 mm, the wrinkling becomes visible in the experiment, and thus the wrinkling was defined to occur.

![Figure 2: Relationship between calculated wrinkle height and punch stroke for $C=110\%$ and $L=10\ mm$](image)

The calculated distributions of the strain in the width direction for $C=110\%$ and $L=10\ mm$ are illustrated in Figure 3. The strain in the width direction in the shrinkage flanging is compressive, and the strain has a peak in the vicinity of the corner of the sheet. When the strain in the width direction exceeds a critical value, the wrinkling occurs.

![Figure 3: Calculated distributions of strain in width direction for $C=110\%$ and $L=10\ mm$](image)
The flanges in the bent sheet for $\alpha=0$ and $30^\circ$, $C=110\%$ and $L=10$ mm obtained from the experiment are shown in Figure 4. For the shrink flanging using the flat punch of $\alpha=0^\circ$, the corner of the sheet wrinkles due to the excessive compressive stress. No wrinkling occurs for the punch having gradual contact of $\alpha=30^\circ$.

Figure 4: Flanges in bent sheet for $\alpha=0$ and $30^\circ$, $C=110\%$ and $L=10$ mm obtained from experiment

A comparison between the experimental and calculated wrinkling heights is illustrated in Figure 5. As the projection angle of the punch increases, the wrinkle height decreases. The calculated wrinkle height is in good agreement with the experimental one.

Figure 5: Comparison between experimental and calculated wrinkle heights for $C=110\%$ and $L=10$ mm

4. Results for punch having gradual contact

The distribution of the change in thickness obtained from the experiment for $C=110\%$ and $L=10$ mm is illustrated Figure 6. The change in thickness is the highest in the vicinity of the corner of the sheet due to the compressive stress. As the indentation angle of the punch increase, the peak change in thickness decreases, i.e. the decrease in compressive stress.
Figure 6: Distribution of the change in thickness obtained from the experiment for C=110% and L=10 mm

The relationship between the wrinkle height and flange length obtained from the experiment for C=110% is illustrated in Figure 7. For α=30°, the limiting flange length is 11 mm, whereas those for α=0 and 15° are 9 mm.

Figure 7: Relationship between wrinkle height and flange length obtained from experiment for C=110%

The relationship between the wrinkle height and flange length obtained from the experiment and calculation for α=30° is shown in Figure 8. For C=110%, the wrinkling is successfully prevented up to L=11 mm, whereas the limiting flange lengths for C=100% and 120% are 9 and 8 mm, respectively.
The relationship between the bending load and stroke obtained from the experiment and calculation and the deformation behavior obtained from the experiment for \( C=110\% \) and \( L=10 \text{ mm} \) is shown in Figure 9. As the projection angle decreases, the peak bending load decreases due to the gradual contact between the punch and sheet. The calculated bending load for \( \alpha = 0 \) and 30° are in good agreement with the experimental one.

![Figure 8: Relationship between wrinkle height and flange length obtained from experiment and calculation for \( \alpha = 30^\circ \)](image)

**Figure 8:** Relationship between wrinkle height and flange length obtained from experiment and calculation for \( \alpha = 30^\circ \)

![Figure 9: Relationship between bending load and stroke obtained from experiment and calculation and deformation behavior obtained from experiment for \( C=110\% \) and \( L=10 \text{ mm} \)](image)

**Figure 9:** Relationship between bending load and stroke obtained from experiment and calculation and deformation behavior obtained from experiment for \( C=110\% \) and \( L=10 \text{ mm} \)

5. Conclusions
The wrinkling in the shrink flanging of the ultra-high strength steel sheets was prevented by the punch having gradual contact. For a projection angle of 30° in the punch having gradual contact, the limiting flange length was 11 mm, whereas that for flat punch was 9 mm. It was found that the punch having gradual contact is effective in preventing the occurrence of wrinkling in the shrinkage flanging.

For the shrink flanging, compressive strain at the corner of the flange for JSC980 sheet was reduced by 20% during the shrinkage flanging using a punch with gradual contact. In the shrinkage flanging using the gradual contact punch, the flange height limit without wrinkling is improved by 27% compared to the flat punch for ultra-high strength sheet JSC980. For the shrinkage flanging using the gradual contact punch the height of the wrinkles can be reduced by reducing the apex angle of the punch. The maximum forming load for shrink flanging using gradual contact punch was decreased 43 percent compared to the flat punch.
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