520 Press forming of high tensile strength steel sheet — Hat channel product combined straight part with curved part in longitudinal direction —

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Abstract: This paper deals with the complexly-shaped hat channel product, which combines a straight part with a curved part in the longitudinal direction. Twist in the longitudinal direction is the most typical and serious of all dimensional inaccuracies in the product. Influencing factors in twisting can be classified into residual stress and residual moment. At first by varying forming conditions, such as blank holding force and cushion force, the influence of the residual stress generated on shrink and stretch flange on twist are investigated. Contrary to our expectation, the residual stress had almost no relation to twist. Subsequently, by cutting flanges and side wall to release the residual moment, the influence of the residual moment on twist was investigated. It was observed that the residual moment plays an important role on twist. Based on the above, some parts of die radius are varied to control residual moment. As a result, it is experimentally found that twist decreased.

Key Words: Press Forming, High Tensile Strength Steel sheet, Hat Channel, Twist in the Longitudinal Direction

1. INTRODUCTION

Lightness and high rigidity are required for automotive body structure. To achieve these requires, high tensile strength steel sheet is used for car reinforcement parts. But, processing high tensile strength steel sheet becomes more difficult as its strength is raised, and the dimensional inaccuracies of product cause trouble, such as spring back [1].

This paper deals with hat channel product, a product which combines a straight part with a curved part in the longitudinal direction. Twist in longitudinal direction is the most typical and serious of dimensional inaccuracies.

Generally, influencing factors on twist in the longitudinal direction can be classified into residual stress and residual moment. It can be considered that the residual stress acts to create twist in the longitudinal direction in materials such as hat product made of thin sheet [2]. However, the sheet used in this study is not thin. Hence, there is need to consider how the residual moment acts on twist in the longitudinal direction. By varying forming conditions, the mechanism of occurring twist in the longitudinal direction is investigated. Moreover, the strategy to decrease twist in the forming process is examined.

2. OUTLINE OF EXPERIMENT

2.1 Material and product shape

60kgf-class high tensile strength steel sheet (Dual Phase) is used. Material properties are shown in **Table 1**. Thickness is 1.6 mm. And other dimensions are shown in **Fig.1(a)**. Three kinds of product are shown in **Fig.1(b),(c),and(d)** which shows a straight part, a curved part, and combined product which has both straight part and curved part.

Table 1 Material properties

Yield stress σ_y MPa	Young's module E GPa	F value MPa	n value
432	210	1060	0.20

Fig.1 Three kinds of product

2.2 Forming conditions

A hydraulic press machine was used for forming. Punch velocity was 12 mm/s. Forming conditions are shown in Table 2. Punch force was 2500 kN, blank holding force was 150, 450 kN, and cushion force was 30, 500 kN. Outside die radius (called shrink side) and inside die radius (called stretch side) was 6 mm, punch radius was set at 6 mm. Clearance ratio was set at 1.1, which is ratio of between die and punch and thickness.

Fig. 2 Forming apparatus

Table 2 Forming conditions

Punch force kN	2500
Blank holding force kN	150, 450
Cushion force kN	30, 500
Outside die radius mm	6
Inside die radius mm	6
Punch radius mm	6
Clearance ratio	1.1

2.3 Measurement method

Curvature of side wall shown in Fig. 3 was measured, using contour measuring instruments. Curvature $1/\rho$ was calculated by circular arc approximation from measured data. Twist in the longitudinal direction shown in Fig. 3 was measured, using a three-dimensional coordinate measuring machine. Twist angle ϕ was defined as the angle at each section with section 5. The nominal strain distribution in section 5 was calculated from the interval of the marking line, using strain measurement film. Interval of marking line is 5 mm at straight part, and 1 degree at curved part. It is measured at an interval of 10 mm, as shown in Fig. 4. Center position moved during the forming, as shown in Fig. 5. Therefore flanges did not deform uniformly. Hence, movement of centerline was examined and when centerline moved toward shrink side, it was defined positive, and when stretch side, negative.

3. RESULT OF EXPERIMENT

3.1 Influence of blank holding force (BHF)

By varying blank holding force (BHF) under constant cushion force (CF) of 30 kN, the influence of the

Fig. 3 Measurement index

Fig. 4 Measurement point

Fig. 5 Movement of center position

residual stress generated on shrink and stretch flange on the curvature on side wall, movement of centerline, and twist was investigated.

Fig. 6 shows the variation of the movement of the centerline. Under BHF of 150 kN, about 5.5 mm of movement of centerline occurs in section 5, and, on the other hand, about -5 mm of movement of centerline occurs in section 1. Only small difference was observed when BHF was modified to 450 kN, compared to that with BHF of 150 kN.

Fig. 6 Movement of center line (CF 30kN)

Fig.7 Distribution of twist (CF 30kN)

Fig.8 Distribution of strain in section 5 (CF 30kN)

Fig.9 Distribution of curvature (CF 30kN, shrink side)

Fig.10 Distribution of curvature (CF 30kN, stretch side)

Fig.7 shows the variation of twist, 4 degrees of twist direction in section 1 occurs at both BHF of 150 kN and 450 kN. The two results are almost identical.

Fig.8 shows the variation of longitudinal strain, under BHF of 150 kN, about 5 % longitudinal strain on shrink flange occurs. As it approaches from flange to bottom center, the absolute value of the strain decreased. On the other hand, 7 % of longitudinal strain on stretch flange occurs. And the same remark as the stretch side can be made. Under BHF of 450 kN, relatively about 3 % of longitudinal strain on shrink side increased compared to that with BHF of 150 kN, and relatively about 5 % of longitudinal strain on stretch flange increased compared to that with BHF of 150 kN.

Fig.9, and Fig.10 shows the variation of curvature, under BHF of 150 kN, about 0.005 mm⁻¹ of curvature in section 1 occurs, and about 0.003 mm⁻¹ of curvature in section 5 occurs. Under BHF of 450 kN, curvature does not vary relatively.

The results obtained in this section can be summarized that, under the higher BHF of 450 kN, the amount of longitudinal strain increased. However, twist did not vary relatively. Hence, the blank holding force had almost no relation to twist.

3.2 Influence of cushion force (CF)

By varying cushion force (CF) under constant blank holding force (BHF) of 150 kN, the influence of the residual stress generated on shrink and stretch flange on the curvature on side wall, movement of centerline, and twist was investigated.

At first, Fig.11 shows the variation of movement of centerline, under CF of 30 kN, about 5.5 mm of movement of centerline in section 5 occurs on the shrink side, and on the other hand, about 5 mm of movement of centerline in section 1 occurs on the stretch side. When CF is modified to 500 kN, movement of centerline on all sections is hardly seen.

Fig.11 Movement of centerline (BHF 150 kN)

Fig.12 Distribution of twist (BHF 150 kN)

Fig.13 Distribution of strain in section 5 (BHF 150 kN)

Fig.14 Distribution of curvature (BHF 150 kN, shrink side)

Fig.15 Distribution of curvature (BHF 150 kN, stretch side)

Fig.12 shows the variation of twist, 4 degrees of twist in section 1 occurs both CF of 30 kN and 500 kN. The two results are almost identical.

Fig.13 shows the variation of the longitudinal strain, under CF of 30 kN, about 5 % of longitudinal strain on shrink flange occurs. As it approaches from flange to bottom center, the absolute value of the strain decreased. On the other hand, 7 % of longitudinal strain on stretch flange occurs. And the same remark as the stretch side can be made. Under CF of 500 kN, relatively about 3 % of longitudinal strain on shrink side increased compared to that with CF of 30 kN, and relatively about 7 % of longitudinal strain on stretch flange increased compared to that with CF of 30 kN.

Fig.14, and Fig.15 shows the variation of curvature, under CF of 30 kN, about 0.005 mm⁻¹ of curvature in section 1 occurs, and about 0.003 mm⁻¹ of curvature in section 5 occurs. Under CF of 500 kN, 0.002 mm⁻¹ of curvature in section 5 on shrink side is decreased relatively, and about 0.003 mm⁻¹ on stretch side is decreased.

Under the influence of high CF, strain in the longitudinal direction increased 5~7 %. And it can be said that the amount of curvature decreased as tension increased in the vertical direction. But twist did not vary.

The results obtained in this section can be summarized that under higher CF of 500 kN, the amount of the longitudinal strain increased. However twist did not vary relatively. Hence, the cushion force had almost no relation to twist.

4. MECHANISM OF OCCURRING TWIST AND STRATEGY TO DECREASE

4.1 Deformation behavior by slitting flange and side wall

By slitting flanges and side wall to release the residual stress and moment, the influence of these on twist was investigated. Relation between curvature and twist are shown.

Fig.16 Slit off flange and side wall

As shown in Fig.16, 17 sections were slit off. Firstly, shrink flange was slit off, and then side wall on shrink side is slit off. And the same way as the stretch side is taken. Fig.17 shows the variation of curvature, before slitting, about 0.006 mm⁻¹ of curvature in section 1 occurred, and about 0.003 mm⁻¹ of curvature in section 5 occurred. By slitting shrink flange, curvature varied little

relatively. And slitting side wall on shrink side, about 0.004 mm^{-1} of curvature occurred, when the residual moment was released. Curvature on stretch side did not vary by slitting product.

Fig.18 shows the variation of twist, before slitting, 4 degrees of twist in section 1 had been occurred. By slitting shrink flange, 3 degrees of twist in section 1 occurred, and by slitting side wall on shrink side, 1 degree of twist occurred.

Fig.19 shows the variation of curvature, before slitting, about 0.006 mm^{-1} of curvature in section 1 occurred, and about 0.003 mm^{-1} of curvature in section 5 occurred. By slitting stretch flange, curvature varied little. And slitting side wall on stretch side, about 0.004 mm^{-1} of curvature occurred, when the residual moment was released. Curvature on shrink side does not change by slitting the product.

Fig.20 shows the variation of twist, before slitting, 4 degrees of twist in section 1 have been occurred. By slitting stretch flange, twist did not vary, and by slitting side wall on stretch side, 5 degrees of twist in section 1 occurred.

It is observed that the residual moment plays an important role on twist.

4.2 Mechanism of occurring twist

Experiment results show that twist does not occur in straight product. 0.7 and 2.0 degrees of twist occur in section 3 in curved product and combined product, respectively. This increase of the amount of twist in the combined part can be considered as the result of the connection of curved part with straight part.

The residual moment is released by slitting side wall on shrink side, and side wall is opened outward owing to spring back. And simultaneously twist angle is decreased.

When side wall is opened owing to spring back, the circumferential length is varied, as shown in Fig.21. On shrink side, the circumferential length increases, and on stretch side it decreases. But the extensional deformation does not occur on shrink side, and the compressible deformation does not occur on stretch side. Hence, displacement occurs from A to B on shrink side, and

Fig.21 Displacement owing to spring back

Fig.17 Distribution of curvature, slitting shrink side

Fig.18 Distribution of twist, slitting shrink side

Fig.19 Distribution of curvature, slitting stretch side

Fig.20 Distribution of twist, slitting stretch side

displacement occurs from C to D on stretch side as shown in Fig.21. It can be considered that the displacement of both shrink side and stretch side makes twist.

4.3 Strategy to decrease twist quantity

Aiming to decrease the residual moment which cause spring back, the new die, which includes 2 mm of die radius in longitudinal direction, is set up as shown in Fig.22. 2 mm of die radius is set from section 1 to section 3 on shrink side, and from section 3 to section 5 on stretch side. This die radius increased from 2 mm to 6 mm smoothly. Relation between curvature and twist on all sections are compared with new die and conventional die.

Fig.23, and Fig.24 shows the variation of curvature, about 0.006 mm^{-1} of curvature occurs in section 1, and about 0.003 mm^{-1} of curvature occurs in section 5 on both shrink side and stretch side with the conventional die. As shown in Fig.23 on the shrink side, about -0.002 mm^{-1} of curvature occurs in section 1, and about 0.002 mm^{-1} of curvature occurs in section 5 with the new die. As shown in Fig.24 on the stretch side, about 0.004 mm^{-1} of curvature occurs in section 1, and about -0.001 mm^{-1} of curvature occurs in section 5 with the new die. As a result, twist is decreased from 4 degrees to 1 degree, as shown in Fig.25.

Based on the above, the side wall is opened less than that with conventional die, if the residual moment is decreased. Then twist is decreased.

5. CONCLUSION

When a hat channel product combining straight part with curved part, twist in the longitudinal direction occurs. The factors in twisting are investigated.

- (1) By varying the blank holding force and cushion force, the amount of the longitudinal strain increased about 5 % relatively. However twist varied little. Hence, the blank holding force and the cushion force have almost no relation to twist.
- (2) By slitting flanges and side wall to release the residual stress and moment, 3 degrees of twist decreased. Hence, the residual moment plays an important role in twist.
- (3) Aiming to decrease the residual moment, 2mm of die radius was set up at section 1 on shrink side and at section 5 on stretch side. Side wall opens less, if the residual moment decreases. As a result, twist was decreased by 3 degrees.

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Fig.22 The new die which includes 2 mm

Fig.23 Distribution of curvature (shrink side)

Fig.24 Distribution of curvature (stretch side)

Fig.25 Distribution of twist

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