Residual stress around cut end of hat steel channel by roll forming

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Abstract

A hat steel channel is useful tool in building construction technology and it mainly fabricated by roll forming. A three-dimensional finite element simulation was conducted to investigate cut end deformation of hat steel channel and its mechanism. When hat steel channel is cut off, the cutting edge will change by the release of residual stress. This change is called cut end deformation. For the steel channel, the top end will close and tail end will open. In contrast, for the hat steel channel, both the top end and the tail end will open. Therefore, this paper will discuss about residual stress occurs on the hat steel channel by simulation results.

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1. Introduction

The rapid development of housing construction is aided by the improvement of housing construction technology. One useful tool in house construction is hat steel channel. This kind of channel steel is typically fabricated via roll forming. One of the common problems in the handling of the steel channel is when it is cut to the desired length, the channel will deform. This is believed to be due to the release of residual stress. If the deformation at the cutting edge of the product is wide, this will create problems in joining parts together, as is needed when assembling...

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components, and in butting the channels side by side, as is needed when building panels. Also, it can create product application and appearance problems. Moreover, when carrying out a flying cut, if the edge of the product changes immediately after cutting, this will lead to cog breakage. Therefore, it is necessary to amend the size of the edge at which cut end deformation occurs at both the front end and the tail end. This will lead to poor production efficiency.

Many reports have described pipe end deformation. Kato et al. [1] describes measuring the dimensions of the cutting planes of channel steel to determine their tendency to develop closing front end and opening back end deformations. In addition, some experiment have been performed regarding cut end deformation. Mihara et al. [2] conducted experiments regarding the formation of U-shaped ribs, finding that inserting an inner roll of small diameter at the last stand was effective in avoiding end deformation. Conducting a series of forming experiments on channel, hat, and C-channel steels, Ona et al. [3] concluded that the residual bending moment and the residual torsional moment were the main factors in pipe end deformation. Holmas et al. [4] mentioned cut end deformation caused by internal stresses, which are balanced while the section is continuous but become imbalanced as soon as the section is cut. Because the author did not have sufficient data to specify these internal stresses, some factors that influence cut end deformation remain to be identified. Previously, research on the cut end deformation of hat-shape channel steel via roll forming was performed by Nagamachi et al. [5, 6]. This paper continues the prior research and will focus on the relationship between the cut end deformation of hat steel channel and residual stress, together with the mechanism of cut end deformation. The use of the roll forming method without cut end deformation is desired.

2. Experiments and FE Simulation

Fig. 1 presents a schematic view of the forming process used in this study. A metal sheet is bent by the corner position of the roll forming from rolls No.1 ~ No.6. First, the metal sheet is bent. Then, a flange is formed in this process. Finally, the product, which has a hat channel, is fabricated. The rolls and their dimensions are presented in Fig. 2. Table 1 summarizes the mechanical properties of the sheet metal, as derived from tensile tests. In the experiment, the bottom roll is driven, and the top roll is non-driven. The velocity at the front end of the metal sheet is $V_z = 24$ mm/s, which is set as a boundary condition in the simulation. The angular velocity of the roll is computed so that the torque will be almost zero. For the coulomb friction between the metal sheet and the roll, a coefficient of friction of 0.12 was used in the simulation. The longitudinal length of the analysis domain is 750mm, which is double the length of the interval of each stand.

![Fig. 1. Schematic diagram of forming process.](image)
Then, the cutting processes were simulated as follows: (1) Select one section in the stationary deformation region during the forming process; (2) Transfer the coordinates and stress-strain data in a longitudinal direction to generate a model that has a uniform sectional shape in the longitudinal direction; (3) Remove the boundary condition at both ends to allow deformation at the cutting section; and (4) Determine the cut end deformation caused by the displacement of nodes, which produces a force imbalance. The analysis domain for FE analysis was cut by hexahedral elements with eight nodes. Numerous solid elements in the thickness direction are necessary to calculate the deformation of elastic recovery. However, this makes the computation time extremely long. Three elements were created in the thickness direction. This was the minimum number of elements that could be used to produce an analysis of elastic recovery, as was understood by examining the previous report [5]. The total number of elements was 30,000~47,000. An FE simulation was conducted using a static implicit scheme, which was applied to the transient elasto-plastic analysis. A DEFORM-3D Ver. 10.1 was used to perform the calculations. In the calculation, Young’s modulus was 206.8 GPa, Poisson’s ration 0.3, Yield stress was 250.8 MPa, n-value was 0.250 and tensile strength was 388.8 MPa.

3. Result and Discussion

3.1. The effect of lip on cut end deformation

The definition of a sign which express cut end deformation is present in Fig. 3. In the Fig. 3, $x_0$ is standard width, $x_F$ is top end width, $x_T$ is the tail end width. Fig. 3 also demonstrate the direction for each plane where longitudinal direction shown by $l$ direction, thickness shown by $t$ direction and width (transversal) direction shown by $w$ direction. Next, the relation between cut end deformation and lip’s length is express in the Fig. 4. Also, the open symbol ($\diamond$, $\triangle$) stands for the width of the cutting section of the front end, and the solid symbol ($\bullet$, $\blacksquare$) stands for the width of the cutting section of the back end. From the figure, we can say that the simulation results agree with the experimental[3] results relatively well.
Fig. 3 depicts the relationship between the width of the cutting section and lip length. The results obtained show that the deformation zone changes when the lip length changes and that the front end and back end show different amounts of deformation. When $F=0$ mm, the front end value, $(x_F - x_0) / 2$, is negative, and the tail end value, $(x_B - x_0) / 2$, is positive, whereas when $F=3$ mm, 9 mm, 16 mm or 23 mm, both the $(x_F - x_0) / 2$ and $(x_B - x_0) / 2$ values are positive. The results indicate that steel channel without a lip ($F=0$ mm) has a closing deformation at the front end and an opening deformation at the tail end, while channel steel with a lip ($F=3$, 9, 16 or 23 mm) has an opening deformation at both front and tail end. The back end values are larger than the front end values, suggesting a larger opening deformation at the back end. A simulation was performed for 3 mm of lip length (this was not performed experimentally) and $t=0.8$ mm, as demonstrated in Fig. 4. Interestingly, a channel with even a small lip will result in an opening deformation at the back end.

It is believed that cut end deformation of product formed by roll forming is cause by shear stresses in thickness-longitudinal direction and longitudinal-peripheral direction (1990) [9]. Yet very few studies have examined and explain in detail the generation mechanism of cut end deformation and the causes. Next session, 3.2 therefore, set out to discuss in details on residual stress that causes cut end deformation of hat steel channel.

### 3.2. The effect of residual stress on cut end deformation

![Distribution of residual shear stress $\tau_{wl}$ (shear stress in transversal-longitudinal) of channel being formed by No. 5 rolls: (a) $F=0$ mm; (b) $F=9$ mm.](image)
We will discuss the residual stress by referring to Fig. 5(a) and (b) above. Fig. 5 depicts the distribution of residual stress $\tau_{tw}$ (shear stress in the transversal-longitudinal direction) of the channel being formed. In Fig. 5, the colour red shows tensile stress and colour blue shows compressive stress. First, we discuss the case of a channel without a lip, $F=0$mm. As shown in Fig. 5(a), regarding the shear stress for a channel without a lip in the transversal-longitudinal $\tau_{tw}$ direction, the occurrence of a large tensile residual stress at the inner plane and a large compressive residual stress at the outer plane can be seen.

When $F=0$mm, the inner plane $\tau_{tw}$ is positive, and the external plane $\tau_{tw}$ is negative. The flange becomes bent, rebent, and reverse bent by the effect of roll forming in the longitudinal direction. Given the position of the centre of roll rotation, the lower part will receive the last reverse bend, which is the reason residual stress occurs. Based on the detailed simulation results, it is believed that the bend return is a twist return and that the twisting moment affects the flange of the product. If the residual twisting moment is released, the front end will be closed, and the back end will be open.

During the roll forming process, concave, convex and reverse bending deformations of the flange take effect and cause the bending lines to diverge from the contact point between the top roll and the corner of the flange. The reverse bending deformation is caused by the bending moment and the twisting moment. The residual twisting moment is also known as the residual in-plane shear stress. These moments remain on the flange. When channel steel is cut, the release of the bending moment results in the opening of both the front end and the tail end. At that moment, in the $F=0$mm case, the release of the twisting moment makes the flange close at the front end and open at the tail end.

Fig. 6 shows that for a deformation that opens the front end and the back end, the in-plane value is negative for the inside and the external plane value is positive for the outside in the large domain of the flange. This residual stress in the longitudinal direction, along with the reverse bending in longitudinal direction, is the reason the bending moment remains in the flange of the product. If the residual bending moment is released, both the front end and the back end will open.

On the other hand, when $F = 9$ mm, 16 mm, or 23 mm, the in-plane $\tau_{tw}$ will be positive when $14 \text{ mm} < c < 40 \text{ mm}$ and negative when $40 \text{ mm} < c < 50 \text{ mm}$. The sign of external plane $\tau_{tw}$ will be the opposite of the in-plane value’s sign. The bottom part of the flange ($c=14 \text{ mm}$–$40 \text{ mm}$) and the top part of the flange ($c = 40 \text{ mm}$–$50 \text{ mm}$) have different residual twisting moments. If the moments are released, cut end deformations with reversed openings and closings will occur on the top and bottom parts. It is believed that the torsion moments, which are mutually offset, are the reason that the deformation that occurs is reduced.
4. Conclusion

1) A hat steel channel without lip will flair in (closing) at the top end and flair out (opening) at the tail end when cut off into component, differ to hat steel channel with lip will flair out (opening) at the both top end and the tail end.

2) Large residual shear stress in the transversal-longitudinal direction $\tau_{wl}$ at the edge affecting the outer and the inner layer result in cut end deformation. For hat channel with lip, opposite direction of residual twisting moment occurs at the upper part and lower part of flange. Those stress and moments offset each other making the cut end deformation small at cutting edge.

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