Influence of Process Parameters on the Forward Slip of Cup during Roll Forming

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Abstract. The effect of friction coefficient, reduction of thickness, forming speed, roller diameter on the coefficient of forward slip at the rim of the roller during cup roll forming was studied by numerical simulation. The results show that during roll pre-forming, the friction coefficient and forming speed have little effect on the coefficient of forward slip, and the reduction of thickness and the diameter of the roller have a greater influence on the coefficient of forward slip; as the reduction of thickness increases, the coefficient of forward slip increases; as the roller diameter increases, the coefficient of forward slip increases first and then decreases. The coefficient of forward slip during the roll pre-forming of cup is much larger than that of roll forging. During roll shaping, the process parameters have little effect on the coefficient of forward slip and its value is close to zero, that is, the axial length of the roll shaped part is almost equal to the arc length of the roller rim. The accuracy of numerical simulation is verified by experiments, and the error between the numerical simulation and experiment is less than 1%.

1. Introduction

Metal cup with variable wall thickness not only have extensive applications, but also need large scale production. Of parts such as drill pipe joints and projectile bodies, whose final shape or the shape in a certain step during the forming process needs to be a variable wall thickness. Cup with variable wall thickness usually is traditionally manufactured using the production process of plastic forming and then machining [1-6]. However, the material utilization rate is relatively low using this traditional production process.

In order to increase the material utilization rate of cup with variable wall thickness and meet the requirements of its production efficiency, a roll forming method is proposed and the schematic of roll forming is shown in Figure 1 [7-10]. At the time of roll forming, the punch is installed under the movable ram of the hydraulic press. The billet, which is pushed by the downwardly moving punch, makes the pre-forming rollers to rotate and the variable wall thickness of the cup is formed by the specific groove shape on the surface of the rollers. In order to avoid the formation of a thin flash, a triangular flash groove is designed between the adjacent pre-forming rollers (as shown in Figure 2). As a result, the metal that flows into the gap between the rollers will form a triangular flash, which can be eliminated by the shaping rollers installed below the pre-forming rollers. The shaping rollers rotate at an offset angle with respect to the forming rollers.
During the roll forming process, due to the deformation of metal, the speed of the metal flowing out of the roller is different to that of the roller, which causes the arc length of the roller groove to be inconsistent with the axial dimension of the part after roll forming. Therefore, precise design of the arc length of roller is the key to ensure the axial dimension of the roll formed parts. In this paper, the coefficient of forward slip (S), which is used for the design of the arc length of the roller groove, is studied. During roll forming, the radius, bite angle, and groove arc length of the middle and rim of the roller are different, so the coefficient of forward slip also is different. In this paper, the research was mainly conducted on the rim of the roller.

2. Numerical Simulation

2.1. Model of Numerical Simulation

The Deform-3D finite element software was used to simulate roll forming. The model of numerical simulation for roll forming is shown in Figure 1, which consists of punch, billet, and rollers. The billet is a plastic body, and the rollers and punch are rigid bodies. The billet for roll forming and roll formed cup with curved rotary profile are shown in Figure 3. The material of billet is pure aluminum 1060. The initial temperature of the billet and the ambient temperature are 20 °C. The arc lengths of the middle of the roller groove corresponding to the axial length L of the roll formed part all are 53.2 mm and the arc length Lm at the rim of roller is different when the radius of roller changes. The roller for shaping is same with that of pre-forming. The speed of punch is v. The friction between the billet and the rollers and punches is based on a shear friction model and the friction coefficient is respectively μ₁ and μ₂.
2.2. Results of Numerical Simulation

The roll formed parts are shown in Figure 4.

![Figure 4. Roll formed cup of numerical simulation](image)

2.2.1. Pre-forming

Table 1 shows the axial length $L$ and the coefficient of forward slip ($S$) of the roll pre-formed parts with different process parameters. The coefficient of forward slip in the table is calculated by the following equation:

$$S = \frac{L - L_m}{L_m} \times 100\%$$  \hspace{1cm} (1)

where $L$ is the axial dimension of the part after roll forming, $L_m$ is the corresponding arc length of roller groove.

The three parameters such as the punch radius (inner diameter of the billet), the wall thickness of the roll formed part, and the wall thickness of the billet are essentially changes in the reduction of thickness during roll extrusion. Reduction of thickness can be calculated by the following equation:

$$\Delta t = \frac{t_0 - t_1}{t_0} \times 100\%$$  \hspace{1cm} (2)

where $t_0$ is the wall thickness of the billet, $t_1$ is the wall thickness of the roll formed part.

| $R$ (mm) | $L_m$ (mm) | $r_0$ (mm) | $t_1$ (mm) | $t_0$ (mm) | $\mu_1$ | $\mu_2$ | $v$ (mm/s) | $L$ (mm) | $S$ (%) |
|---------|-----------|------------|------------|------------|---------|---------|-----------|---------|-------|
| 156     | 65.35     | 45         | 18         | 22         | 0.3     | 0.3     | 60        | 70.82   | 8.37  |
| 156     | 65.35     | 45         | 18         | 27         | 0.3     | 0.3     | 60        | 73.88   | 13.05 |
| 156     | 65.35     | 45         | 18         | 32         | 0.3     | 0.3     | 60        | 77.39   | 18.42 |
| 156     | 65.35     | 50         | 13         | 22         | 0.3     | 0.3     | 60        | 73.49   | 12.46 |
| 156     | 65.35     | 55         | 8          | 22         | 0.3     | 0.3     | 60        | 74.69   | 14.29 |
| 156     | 65.35     | 45         | 18         | 22         | 0.2     | 0.3     | 60        | 70.66   | 8.13  |
| 156     | 65.35     | 45         | 18         | 22         | 0.05    | 0.3     | 60        | 70.38   | 7.70  |
| 156     | 65.35     | 45         | 18         | 22         | 0.3     | 0.4     | 60        | 70.07   | 7.22  |
| 156     | 65.35     | 45         | 18         | 22         | 0.3     | 0.5     | 60        | 69.72   | 6.69  |
| 176     | 63.7      | 45         | 18         | 22         | 0.3     | 0.3     | 60        | 72.52   | 13.85 |
| 195     | 62.12     | 45         | 18         | 22         | 0.3     | 0.3     | 60        | 68.40   | 10.11 |
| 156     | 65.35     | 45         | 18         | 22         | 0.3     | 0.3     | 40        | 70.77   | 8.29  |
| 156     | 65.35     | 45         | 18         | 22         | 0.3     | 0.3     | 80        | 70.83   | 8.39  |

When the radius of the punch and the wall thickness of the billet change, the initial contact position of the billet and the roller is same, that is, the bite angle is unchanged; when the wall thickness of the rolling billet changes, the initial contact position of the billet and the roller is different, that is, the bite angle changes, and as the reduction of thickness increases, the bite angle increases.
In order to more intuitively observe the influence of different process parameters on the coefficient of forward slip, Table 1 is made into a graph (as shown in Figure 5). It can be seen from Figure 5 that the reduction of thickness has the greatest influence on the coefficient of forward slip, and as the reduction of thickness increases, the coefficient of forward slip increases significantly. The simultaneous change of the bite angle and the reduction of thickness have a greater influence on the coefficient of forward slip than the reduction of thickness alone. The influence of the roller radius on the coefficient of forward slip is also obvious, and as the roller radius increases, the coefficient of forward slip increases first and then decreases. As the friction coefficient between the punch and the billet increases, the coefficient of forward slip also increases. However, the friction coefficient between the billet and the roller has little effect on the coefficient of forward slip.

Figure 5. Influence of process parameters on coefficient of forward slip
billet increases, the coefficient of forward slip increases slightly. As the friction coefficient between the billet and the roller increases, the coefficient of forward slip decreases slightly. The effect of friction coefficient on the coefficient of forward slip is much smaller than the reduction of thickness and the radius of the roller. The punch speed has almost no effect on the coefficient of forward slip. The effect of the above process parameters on the coefficient of forward slip during the roll forming of cup is nearly same with that of roll forging. But the coefficient of forward slip during roll forging is small, generally not more than 6%; the value is large during the roll forming of cup, and the minimum value in the numerical simulation results is greater than 6%. The main reason for this phenomenon is that part of the metal can flow in the direction perpendicular to the axial direction during roll forging, while the metal can only flow in the axial direction when the cup is roll formed.

2.2.2. Shaping
After roll shaping with different process parameters, the axial length L of the cup corresponding to the center of the shaping roller is slightly shorter than the arc length of the rim of the roller, and the axial length L of the cup corresponding to the rim of the shaping roller is slightly longer than the arc length of the rim of the roller, and the average of the two values is 0 to 1 mm larger than the rim arc length depending on different process parameters. It can be seen that the process parameters have little effect on the coefficient of forward slip during the roll shaping. The main reason for this phenomenon is that only a small amount of metal formed by the flash groove of pre-forming roller deforms during the roll shaping process, so the speed of the metal flowing out of the roller is nearly same as the speed of the roller of shaping.

3. Experimental Verification

3.1. Experimental Conditions
Experiments were conducted on the process parameters of the first row of Table 1. The material of billet is 1060 pure aluminum. Roll forming is per roll forming formed on a hydraulic press (as shown in Figure 6). In order to measure the pre-formed part, pre-forming and shaping are performed separately by the same roll forming equipment. At the time of shaping, the flash formed by pre-forming roller need to be aligned with the middle of the shaping roller.

3.2. Experimental Results
The billet for roll forming and the roll formed part are shown in Figure 7. The roll formed parts were measured and the size L is 71.1mm for pre-forming and the average value of size L is 65mm for shaping. Compared with the numerical simulation values of 70.82mm and 65.5mm, the errors between numerical simulation and experiment are respectively 0.4% and 0.8%. It can be seen that the numerical simulation results are accurate.

Figure 6. Equipment of roll pre-forming
Figure 7. Billet and the roll formed part
4. Conclusions
At the time of roll pre-forming, the friction coefficient and forming speed have little effect on the coefficient of forward slip, and the reduction of thickness and the diameter of the roller have a greater influence on the coefficient of forward slip; as the reduction of thickness increases, the coefficient of forward slip increases; as the roller diameter increases, the coefficient of forward slip increases first and then decreases. The coefficient of forward slip during the roll pre-forming of cup is much larger than that of roll forging. During roll shaping, the process parameters have little effect on the coefficient of forward slip and its value is close to zero, that is, the axial length of the roll shaped part is almost equal to the arc length of the roller rim. The accuracy of numerical simulation is verified by experiments, and the error between the numerical simulation and experiment is less than 1%.

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