Research on the influencing factors of small bending radius elbow stamping based on CAE simulation

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Abstract: The elbow with small bending radius is widely used in heating system and line collecting system, but its processing is difficult. Using the way of sheet metal stamping processing half elbows, and then welding the two half elbows is an effective method. There are a series of key parameters in the process of elbow stamping, which directly affect the forming result. Using sheet metal stamping software for stamping simulation, and comparing the effects of the parameters on thinning and principal stresses, we can see the specific effects of different parameters on the shaping. The main influencing factors of elbow stamping include friction coefficient, clearance, blank holding force and sheet metal thickness. For the friction coefficient and blank holder force, it should be selected near the minimum value. For clearance and sheet metal thickness, it is proportional to the forming effect.

1. Introduction
Elbow is one of the important pipe fittings in various pipe structures, which can change the direction of the pipe, improve the flexibility of the pipe, relieve the vibration and binding force of the pipe, and compensate for the thermal expansion[1]. The classification of elbow is varied, and the manufacturing methods and materials used are various. Stamping forming elbow is the earliest application in mass production of seamless elbow forming process, but now it has been replaced by thermal push or other forming process. However, for thin-walled large elbows with bending radius less than 1.5 times of pipe diameter, such processes as thermal push cannot meet the forming requirements. The stamping elbow has good temperature and pressure resistance, and it also has good flexibility. Using the method of stamping to shape the elbow with small radius can make it reach the ideal stress distribution requirement, and the wall thickness of the elbow will be relatively uniform, which can effectively prevent the phenomenon of too thin or too thick in some areas. Software analysis can provide reference for actual production and reduce the high cost of a large number of field experiments. In this paper, firstly, a series of factors that may affect the forming of elbow stamping were listed. Then, the sheet metal forming software pam-stamp was used to conduct the simulation of multiple groups of different parameters. The last, collect the experimental data, and draw charts to obtain the relationship between the influencing factors and the forming effect.

2. Model
This paper takes the elbow with an outside diameter of 476mm and a bending radius of 500mm as an example (Figure. 1). The method is to press the sheet material into a semi-elbow and then weld the two semi-elbows together. The elbow was simulated in the sheet metal stamping simulation software pam-stamp, and the stress distribution and thinning of the elbow were observed. Through the control
variable method, several experiments were carried out to obtain the influence of each parameter on the forming. Figure 2 below shows the stamping die generated by stamping simulation in pam-stamp.

![Stamping Die](image)

**Figure 2. The stamping die**

### 3. Influencing factors

In the sheet metal forming software pam-stamp, the control variable method is used to conduct multiple experiments on the main influencing factors of stamping forming, such as friction coefficient, clearance, blank holder force and thickness. And the obtained data are integrated into the form of the line graph to be shown intuitively.

#### 3.1 Coefficient of friction

There is a friction force between the stamping die and the plate, and the magnitude of the friction force will affect the forming results. The magnitude of friction is related not only to contact forces but also to lubrication[2]. Figure 3 and Figure 4 are the statistical curves of the forming results under different friction coefficients simulated by software. It can be seen that, with the increase of friction coefficient, the thinning of the elbow has a minimum point around 0.08mm, while the main stress of the elbow increases with the increase of friction coefficient.

![Friction Coefficient](image)

**Figure 3. The maximum thinning and friction factor of the curve**

![Maximum Stress](image)

**Figure 4. The maximum principal stress and friction factor curve**

#### 3.2 Clearance

The gap between the plate and the die is usually set at about 5% to 10% of the plate thickness. Too much clearance will affect the accuracy of forming, and too little clearance will increase the difficulty of processing. Through the software simulation experiment, the data is made into a line graph (Figure...
5. Figure 6). It can be seen from the relation curves between maximum thinning and clearance and the relation curves between maximum principal stress and clearance that, with the increase of clearance, the thickness change and the maximum principal stress after forming will become smaller.

![Figure 5. The maximum thinning and clearance of the curve](image)

![Figure 6. The maximum principal stress and clearance curve](image)

### 3.3 The blank-holder force
Blanking force is an important part of the whole stamping process. The optimization of blanking force determines the distribution of sheet metal stress and directly affects the thickness change. The theoretical calculation formula of blank holder force \( F \) is as follows:

\[
F = \frac{0.7Cb^2\sigma_b}{r+t}
\]

Where:
- \( C \) -- the coefficient, generally \( C=1 \sim 1.3 \);
- \( b \) -- the width of the bending part (mm);
- \( t \) -- the thickness of sheet material (mm);
- \( \sigma_b \) -- the tensile strength (MPa) of the material;
- \( r \) -- the bending radius (mm);

However, in practice, the blank holder force is affected by many factors such as material properties, part shape, bending method and stamping die structure, it is difficult to calculate by theoretical formula[3]. It can only be obtained experimentally. And here the data is simulated in pam-stamp. As can be seen from figure 7 and figure 8, when the blank holder force is 0-400kN, the thickness change and the maximum principal stress will increase with the blank holder force, and the minimum value will appear at 700kN. It needs to be explained that when the edge holding force is less than 200kN, a large rebound will occur, the plate will become warped. Therefore, the blank holder force should be around 600kN to ensure the forming effect, and not too small.

![Figure 7. The maximum thinning and BHF curve](image)

![Figure 8. The maximum principal stress and BHF curve](image)
3.4 Thickness of sheet metal

Forming results will be very different when sheet thickness is different, figure 9 and figure 10 show the comparison line chart of the simulated forming results of several groups of plates with different thickness. As can be seen from the figure, the greater the thickness of the sheet metal, the smaller the thinning, so as the principal stress. This feature is very obvious when the thickness is less than 5mm. And it is relatively flat when the thickness is more than 5mm.

Figures 9 and 10. The maximum thinning and sheet thickness curve

4. CAE simulation results under better parameters

Through repeated simulation of the bending under different parameter settings in the sheet metal stamping software pam-stamp, the forming results of the bending with different thickness under different blank pressure, different friction coefficient and different clearance were obtained, and it was presented in the form of MATLAB broken line diagram. By observing the line chart, a group of good parameters was obtained to make the elbow with an outside diameter of 476mm, a thickness of 10mm and a bending radius of 500mm achieve the ideal simulation effect. The parameters are as follows: the blank holder force is 600kN, the clearance is 1mm, and the friction coefficient is 0.08. The simulation results under the parameters are shown in figure 11 and 12 below.

Figure 11. The thinning contour of semi-elbow
5. Conclusion

The setting of parameters in software analysis is very important and directly related to the forming result. Among these parameters, some parameters can be obtained from data and some experience, while others must be obtained through repeated experiments. The software simulation method can greatly reduce the pre-research cost, and the CAE simulation results also prove the accuracy of the experiment when it is under the better parameters.

Through the experiment, we can see:

1. With the increase of friction coefficient, a minimum point occurs in the thinning of the elbow, while the principal stress of the elbow increases with the increase of friction coefficient. When we choose the friction coefficient, two factors should be taken into account and a smaller value should be selected near the extreme point.

2. The smaller the gap, the more difficult the forming, also the greater the sheet material and the main stress after being formed.

3. The blank holder force should not be too small. On the premise of ensuring the forming effect, the blank holder force should be evaluated near the minimum value.

4. The thickness of sheet metal is inversely proportional to the thinning after forming and the magnitude of main stress, and it is very obvious when the thickness of sheet metal is small, and relatively smooth when the thickness of sheet metal is large.

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