

Retraction

Retracted: Numerical Simulation of Hot Stamping Forming of AZ Series Magnesium Alloys and Optimization of Die Process

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This article has been retracted by Hindawi following an investigation undertaken by the publisher [1]. This investigation has uncovered evidence of one or more of the following indicators of systematic manipulation of the publication process:

- (1) Discrepancies in scope
- (2) Discrepancies in the description of the research reported
- (3) Discrepancies between the availability of data and the research described
- (4) Inappropriate citations
- (5) Incoherent, meaningless and/or irrelevant content included in the article
- (6) Peer-review manipulation

The presence of these indicators undermines our confidence in the integrity of the article's content and we cannot, therefore, vouch for its reliability. Please note that this notice is intended solely to alert readers that the content of this article is unreliable. We have not investigated whether authors were aware of or involved in the systematic manipulation of the publication process.

Wiley and Hindawi regrets that the usual quality checks did not identify these issues before publication and have since put additional measures in place to safeguard research integrity.

We wish to credit our own Research Integrity and Research Publishing teams and anonymous and named external researchers and research integrity experts for contributing to this investigation.

The corresponding author, as the representative of all authors, has been given the opportunity to register their agreement or disagreement to this retraction. We have kept a record of any response received.

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- [1] F. Qian, "Numerical Simulation of Hot Stamping Forming of AZ Series Magnesium Alloys and Optimization of Die Process," *Journal of Chemistry*, vol. 2022, Article ID 6484242, 7 pages, 2022.

Research Article

Numerical Simulation of Hot Stamping Forming of AZ Series Magnesium Alloys and Optimization of Die Process

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In order to deal with the bottleneck of poor plasticity and low formability of magnesium alloys at room temperature, a numerical simulation and a die process optimization method based on hot stamping of AZ series magnesium alloys were proposed. Firstly, based on the PAM-STAMP finite element analysis platform, the thermomechanical coupling numerical simulation is carried out for the cross cup-shaped deep drawing, and the changes in the stress and temperature field during the forming process are analyzed. Aiming at the influence of various process parameters on the plastic formability of magnesium alloys, the effects of sheet metal shape, die fillet size, friction factor, and blank holder force on the forming quality were analyzed through experiments. The experimental results show that under the same conditions such as temperature and blank holder force, the numerical simulation method and the mold process optimized in this paper can be used to form parts that are 25% deeper than the traditional process, and the sheet material can be thinned to the maximum at this time. The amount is 0.152 mm, which verifies the correctness and superiority of the method and process in this paper.

1. Introduction

With the development of the automobile and electronic industries, the demand for magnesium alloy products is increasing, especially the demand for magnesium alloy sheets is increasing significantly. The parts produced by the magnesium alloy sheet have good mechanical properties and microstructure properties, and the cost is low. However, because the commonly used magnesium alloys have a hexagonal close-packed crystal structure [1], it has always been considered that magnesium alloys have a very low forming limit value at room temperature and poor stamping performance, making it difficult to draw parts with complex shapes. Therefore, the main processing method is die casting, which is not conducive to protecting the environment.

In recent years, a large number of scholars' studies have shown that when the magnesium alloy sheet is heated to above 200°C, the first-order conical surface of the crystal structure and {1011}, {1021} slip systems are activated, and the plastic deformation capacity begins and improves.

When the temperature is heated to 225°C, the {1122} slip system of the second-stage cone surface is activated, and the plasticity of the magnesium alloy will be further improved [2]. Since temperature is a major factor affecting the plastic deformation of magnesium alloys, many scholars have done a lot of research on hot stamping and finite element simulation of magnesium alloys. However, the research on hot stamping of magnesium alloys is almost limited to cylindrical parts, above models such as square cups and conical cups.

This paper takes AZ31B magnesium alloy as the research object, based on the PAM-STAMP finite element analysis platform, conducts thermomechanical coupling numerical simulation for cross cup-shaped parts, analyzes the stress change and temperature field change in the forming process, and summarizes various processes. The influence of parameters on the plastic formability of magnesium alloys was discussed. The influence of the size and shape of the sheet, the fillet of the die, the friction factor, and the blank holder force on the forming quality was discussed, and a better solution was obtained. The use of numerical simulation

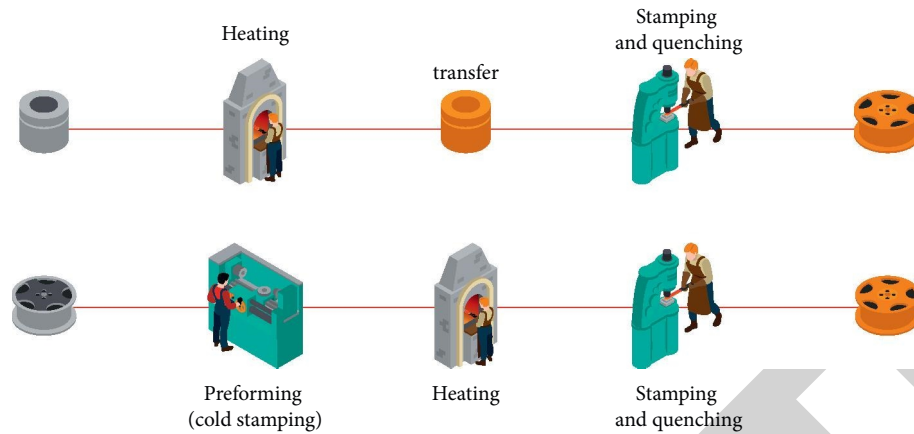


FIGURE 1: The process of stamping and forming AZ series magnesium alloys by different processes.

methods can effectively simulate the forming law of AZ31B magnesium alloy sheet hot drawing, which is of great significance for the design of magnesium alloy hot drawing process parameters and die structure design. Using simulation methods to conduct repetitive experiments can save a lot of time and financial resources. Figure 1 shows the basic process of stamping and forming AZ series magnesium alloys by direct and indirect processes.

2. Literature Review

Tozuka et al. proposed that the thermal incremental forming technology of sheet metal is a flexible forming technology. It heats the sheet to soften the sheet and adopts the idea of layered manufacturing to form a three-dimensional shape along the high line which is divided into a series of two-dimensional layers, and the final shape is obtained after the local deformation of the sheet material layer by layer [3]. Chen et al. pointed out that this method does not need to make molds. For single-piece and small batch production, it is more convenient and faster, and the cost is greatly reduced. It is widely used in product trial production and personalized customized production. It is an important part of advanced manufacturing technology [4].

Chen et al. designed a hot air heating device to heat the sheet material. In order to maintain the consistent temperature of the sheet during the test, a noncontact temperature measurement device was used to continuously monitor the sheet. The forming limits of the material at 20°C, 100°C, 150°C, 200°C, and 250°C were obtained by plane strain tensile and axisymmetric tensile experiments, respectively. Based on these forming limits, truncated cones with different inclination angles were designed and successfully completed at different temperatures. To understand the deformation characteristics in the experiments, a finite element analysis of the forming process was performed. And using the obtained results, a high-inclination round cup was successfully formed using the hot incremental forming method when the forming limit was exceeded [5]. Yang et al.'s team found in their research that the formability of the AZ31 sheet began to sharply improve at 150°C, achieving the effect of forming. At the same time, taking the egg surface

as an example of a free surface, according to the law of thermal incremental forming, the optimal tool path mainly composed of conical and helical shapes was successfully planned, and the egg surface was successfully processed using AZ31 material [6].

Wang et al. used the heat generated by the friction between the tool head and the sheet to heat the magnesium alloy sheet and successfully formed the magnesium alloy inverted pyramid frustum. And the forming performance, hardness, and tensile strength of the formed parts under different tool rotation speeds, feed speeds, and forming angles were measured. The experimental results show that the sheet metal with a forming angle of 25° and a thickness of 0.5 mm is gradually heated by the friction of the tool head. The tensile strength of the formed inverted-square frustum formed part is about 10% higher than that of the general hot incremental formed part [7]. Demler et al. formed AZ31, AZ61, and AZ80 magnesium alloy sheet square cone box-shaped parts by adjusting the spindle speed and feed speed, and the minimum half cone angles could reach 25°, 30°, and 40°, respectively. The AZ31 sheet was thermally incrementally formed by using a six-axis manipulator and a temperature-adjusting heating device. The influence of different heat treatment methods on the formed parts was studied, and the shape and mechanical properties of the formed parts were simultaneously controlled [8].

Li et al. also adopted the method of heating the sheet metal by friction heat with tool head rotation and studied the rotational incremental sheet forming (RISF) method of magnesium alloy sheet at room temperature through experiments. Heat can promote plastic deformation. The team formed square cups with a width of 80 mm, a length of 80 mm, and a length of 25 mm at room temperature, obtained the forming limit curve of RISF considering factors such as tool head radius, and effectively predicted the RISF of magnesium alloy sheets forming limit [9]. The team of Hajbarati et al. developed a set of equipment for performing incremental forming experiments at different temperatures and carried out an appropriate experimental design [10]. Peng et al. specially designed heating and insulation systems for efficient heating control. The device places the heater belt on the outer surface of the mold, and the PID controller

controls three thermocouples placed on different radii, and the heater is controlled by the signal returned by the thermocouple. Insulation systems are placed under the unit to reduce the effect of temperature on the processing equipment. Throughout the test, the temperature of the sheet is relatively uniform, and the temperature difference is less than 5°C [11]. Ubeda et al. studied the influence of main process parameters on the formability of materials through a large number of experiments and strict statistical analysis and concluded that the temperature and the depth of the cutting tool have a great influence on the formability, and the diameter of the tool has a great influence on the formability. The influence of formability is not great. When the temperature is 250°C, the formability is the best. In another paper, the team also proposed a method of using uniaxial tensile experiments to analyze the specimens at the fracture during hot incremental forming at different temperatures to determine the forming limit of the material and carry out experiments for validation [12].

3. Research Method

3.1. Numerical Simulation of Cross-Cup Hot Stamping. The AZ31B magnesium alloy cross cup workpiece, blank and mold model are symmetrical models. From the perspective of improving the calculation speed, the symmetrical model structure is usually adopted, and the 1/4 model is calculated by setting boundary conditions. Based on the pro/E 3D design platform 1/4 model is created and imported into PAM-STAMP to create a finite element model. Thermal model-related parameters are set at the same time and adaptive meshing in the simulation is used. The deep drawing depth is 40 mm, the temperature of the blank holder, die, and sheet metal is 250°C, the temperature of the punch is 100°C, the blank holder force is 800 kN, the stamping speed is 10 mm/sec, and the model factor is 0.12. The equivalent stress is obtained by the following formula [13]:

$$\bar{\sigma} = \sqrt{\frac{1}{2} \left[(\sigma_x - \sigma_y)^2 + (\sigma_y - \sigma_z)^2 + (\sigma_z - \sigma_x)^2 \right]} \quad (1)$$

Then, its dimensionless form can be obtained as

$$\frac{\sigma_z}{\tau} = (\tan \alpha + \cot \alpha) - \frac{\sigma_f}{\tau} \cot \alpha, \quad (2)$$

where τ is the shear stress of the tool head on the sheet.

During the deep drawing process, with the increase of the deep drawing depth, the sheet metal is continuously divided into finer meshes, which is beneficial to the forming of the sheet metal. In this experiment, when the depth of drawing is 8 mm, the grid of the sidewall has been distorted, and when the depth of drawing reaches 12 mm, the grid of the sidewall is distorted to a large extent, indicating that the amount of deformation here is large. In the initial stage of deep drawing, the deformation of the punch fillet is the most severe, which makes the maximum strain value here. In the latter stage of the deep drawing process, the deformation of the sheet material begins to transfer to the side wall and the die fillet, so that the maximum strain occurs at the side wall

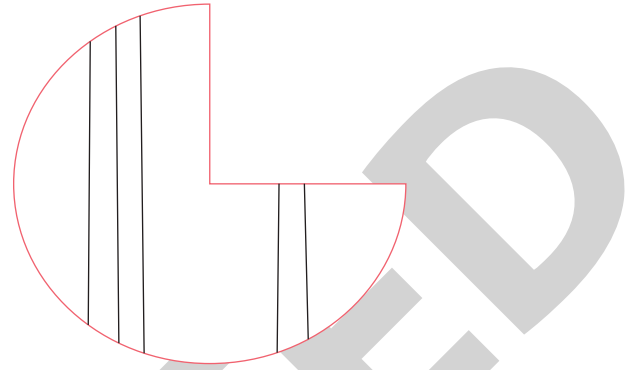


FIGURE 2: Sheet model in Scheme 4.

or the die fillet. Therefore, at this stage, the die fillet and the cylinder wall are the parts where the thinning of the sheet in the postdrawing stage is the largest [14].

3.2. Hot Drawing Process Scheme of Cross-Cup. According to the thermal deep drawing simulation in the previous section, the following process plan is formulated:

Scheme 1: AZ31B magnesium alloy cross cup-shaped 1/4 model, the drawing depth is 40 mm. The temperature of the blank holder ring, the die, and the sheet metal is 250°C, and the temperature of the punch is 100°C; the blank holder force is 800 kN; the punching speed is 10 mm/sec; the model factor is 0.12.

Scheme 2: On the basis of the experiment of Scheme 1, the fillet radius at the flange of the die is changed from 0.5 mm to 1.5 mm, and other conditions remain unchanged. The finite element simulation results show that changing the mold structure; that is, changing the fillet radius of the die flange from 0.5 mm to 1.5 mm, can greatly improve the elongation of the sheet and can form parts with a depth of 25 mm, but it cannot be formed yet. A cross-cup-shaped part with a depth of 40 mm is formed. The reasons for these two situations are analyzed as follows: first, the size of the sheet itself is not enough or the shape needs to be improved; second, the blank holder force is small; third, the model factor is too large [15].

Scheme 3: On the basis of the experiment of scheme 2, the blank holder force was increased from 800 kN to 1000 kN, and other conditions remained unchanged. After the blank holder force is increased, the increase in sheet thickness is obviously controlled. In scheme 2, due to the increase in sheet thickness, the maximum thickness of the sheet is 1.75 mm. After the blank holder force is increased, the maximum sheet thickness is 1.24 mm. The forming performance has also been improved to a certain extent, and the forming depth has been increased from 25 mm to 32 mm. Although the forming quality has been greatly improved after increasing the blank holder force, it is still impossible to draw a cross-cup-shaped part with a depth of 40 mm [16]. The reasons are as follows: first, the size of the

TABLE 1: Optimized hot drawing process plan.

Name	Temperature (°C)	Model factor	Blank holder force (kN)	Die fillet (mm)	Sheet shape and size
Sheet	250	—	—	—	148 mm round sheet
Die	250	0.02	—	1.5	—
Punch	100	0.02	—	—	—
Hemming ring	250	0.02	1000	—	—

sheet is not enough or the shape of the sheet itself is unreasonable; second, it may be that the model factor is too large, resulting in a relatively large amount of sheet metal thinning.

Scheme 4: On the basis of Scheme 3, change the shape of the sheet to a circular sheet with a diameter of 148 mm, as shown in Figure 2. After increasing the size of the sheet, it is possible to form a cross-cup-shaped part with a deep drawing depth of 40 mm, but some sheets are severely thinned, and the results of the finite element simulation of Scheme 4 show that a qualified product cannot be obtained. The reasons for the serious thinning of the sheet may be: first, the model shape of the mold itself; second, the restriction of the shape of the sheet as the shape of the sheet itself affects the flow of the material during plastic deformation; third, the model factor is too big.

Scheme 5: On the basis of the experiment of Scheme 4, the model factor is changed to be smaller, and 0.12 is changed to 0.05. Compared with scheme 4, although the area with severe sheet metal thinning is significantly reduced this time, there is still a thinning area, indicating that changing the model factor to 0.05 still cannot solve the problem of scheme 4. The reasons may be as follows: first, the model shape of the mold itself. The side wall where this area is located is more difficult to flow than other places; secondly, the shape of the sheet is restricted. The shape of the sheet itself affects the flow of material during plastic deformation [17].

Scheme 6: Based on the results of the above experiments, adjust the experimental scheme again and change the model factor to 0.02 on the basis of scheme 5. It can be clearly seen that the phenomenon of sheet metal thickening is basically reduced to a minimum, and the elongation of sheet metal is also greatly improved. When the depth of drawing is 40 mm, the minimum thickness of sheet metal is 0.847342 mm. After analyzing the above sheet material adaptation from the results of grid division, it can be seen that there is no distortion in the grid, which proves that the results of this experiment are reasonable. Through the continuous optimization of the above schemes, the best forming scheme obtained is shown in Table 1 [18].

4. Result Analysis

4.1. *Principal Strain Distribution Cloud Map Analysis.* Figure 3 is the principal strain change curve made by taking 7 different points on the part when the drawing depth is 12 mm. From the curve, it is known that the maximum

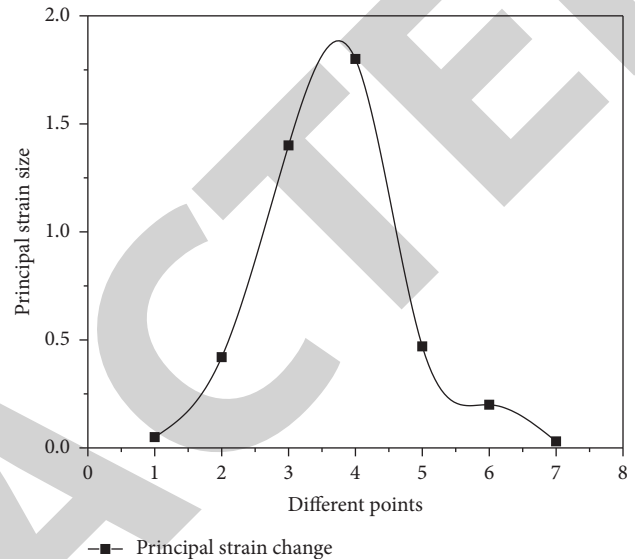


FIGURE 3: Cloud map of principal strain distribution at different drawing moments.

principal strain on the sidewall of the cross cup reaches 1.86. At this time, the thinning of the sheet is very serious, and if the drawing is continued, cracking will occur [19].

4.2. *Sheet Temperature Distribution.* In this experiment, the temperature of the die, sheet metal, and blank holder were all set to 250°C, the temperature of the punch was 100°C, and the drawing speed was 10 mm/sec. Figure 4 shows the temperature of different points on the part when the drawing depth is 12 mm. The curve indicates that the temperature of the sheet decreases from the center of the sheet to the edge of the sheet [20]. This is because in the process of deep drawing, the sheet at 250°C contacts the punch at 100°C, and a lot of heat is generated caused by losses.

4.3. *Sheet Thickness Distribution Cloud Map.* In the process of sheet metal deep drawing, the degree of deformation of each part is not uniform. In the initial stage of deep drawing, the rounded part of the punch first deforms. The corner portions are shifted towards the side walls of the cross cup. Combined with the results of the simulation analysis, it can be seen that the thinning trend in this test is particularly large. Figure 5 is a curve drawn by taking 8 points on the part when the drawing depth is 12 mm [21]. The minimum thickness of some sheets is 0.16952 mm, which means that in this case, the parts we need cannot be drawn [22]. This hot stamping simulation experiment has a large amount of sheet

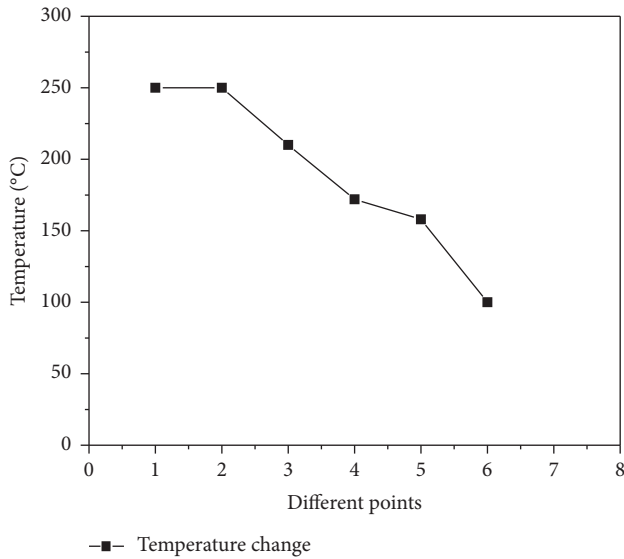


FIGURE 4: Distribution map of sheet metal temperature at different times of deep drawing.

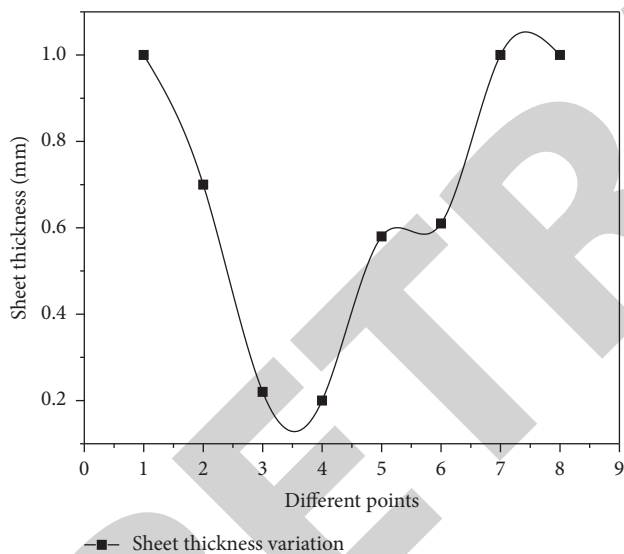


FIGURE 5: Thickness distribution results of sheet metal at different times of deep drawing.

metal thinning, which may be due to the following reasons: too large blank holder force, too large model factor, too small rounded corners of the flange part of the die, and the shape and size of the sheet itself affect its stamping, etc.

By analyzing the distribution cloud map of different properties of the sheet during the above hot stamping process, the following conclusions can be drawn:

- (1) The deep drawing simulation results show that the punch fillet and the concave die fillet are areas with large stress and large deformation. The deep drawing deformation first occurred in the punch fillet and then transferred to the cylinder wall. The rounded part of the punch is the easy-to-crack area in deep

drawing, and the cracking tendency of the cylinder wall is smaller than that of the rounded part of the punch [23]. (2) The finite element simulation results show that with the increase of the model factor, the thinning of the sheet metal is greater. It is once again verified that the larger the model factor, the less conducive it is to the hot drawing of AZ31B magnesium alloy [24]. (3) The simulation results show that the blank holder force is also an important factor. With the change of the blank holder force, the quality of magnesium alloy deep drawing also changes [25]. (4) The simulation results show that the influence of the shape of the blank on the forming performance of the thin plate is very obvious. A reasonable shape of the blank can help to improve the stress and strain distribution of the workpiece during the drawing process, increase the drawing limit, and make the thickness change of the workpiece more comparable, uniform, and of high forming quality. When the shape of the blank is a square trimmed sheet, it can be formed under the process parameters that the temperature of the die, sheet, and blank holder is 250°C, the temperature of the punch is 100°C, the friction factor is 0.12, and the blank holder force is 1000 KN. When the drawing depth is 32 mm, the maximum thinning of the sheet is 0.167 mm. When the shape of the blank is a circular sheet, the temperature of the die, sheet, and blank holder is 250°C, and the temperature of the punch is 250°C. Under the process parameters of 100°C, a friction factor of 0.02, and a blank holder force of 1000 KN, a part with a drawing depth of 40 mm can be formed. At this time, the maximum thinning of the sheet is 0.152 mm. Therefore, it is more appropriate to use circular blanks for this part.

5. Conclusion

In this paper, taking AZ31B magnesium alloy as the research object, based on the PAM-STAMP finite element analysis platform, the thermomechanical coupling numerical simulation is carried out for the cross cup-shaped deep drawing, the stress changes and temperature field changes in the forming process are analyzed, and various processes are summarized. The influence of parameters on the plastic formability of magnesium alloys was discussed. The influence of the shape of the sheet metal, the size of the die fillet, the friction factor, and the blank holder force on the forming quality was discussed, and a better solution was obtained. Using sheet metal hot incremental forming technology to form magnesium alloy sheet, no molds are required to be made, a lot of time and money is saved, and it is very suitable for the design, development, and verification of new products, as well as customized, small batch, multivariety products. It has a very broad application prospect in aviation, aerospace, navigation, automotive engineering, and other fields.

However, at present, this technology has not been widely promoted and applied, and it is in the stage of laboratory

theoretical research. Research can be carried out from the following aspects: (1) In the study of the mechanism of the liquid medium support heating incremental forming process, in order to simplify the calculation, some assumptions are made, which make the actual situation and the calculation results to have a certain deviation. Although they can reflect a certain law change, there is still a certain gap with the actual processing process. In the actual processing process, the influencing factors are very complex, so to achieve industrial application, more detailed research on the mechanism is needed. (2) The final size of the part is generated by the coupling of multiple factors such as springback, material thinning, insufficient forming, and forming path design. Therefore, in-depth research is needed on other factors that affect the accuracy of formed parts. In addition, in order to further reduce the accuracy error, further research can be carried out on the establishment of the accuracy prediction model, the accuracy compensation, and the automatic programming of the machining path. (3) In addition to the factors that affect product quality listed in this paper, there are other factors such as wrinkling, instability, forming microcracks, indentation, metal accumulation, and more in-depth research will be carried out in the future.

Data Availability

The data used to support the findings of this study are available from the author upon request.

Conflicts of Interest

The author declares that there are no conflicts of interest.

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