Three-dimensional Finite Element Simulation and Experimental Verification of Power Spinning of Magnesium Alloy Cylindrical Parts

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Abstract. Spinning technology is an effective method for forming thin-walled long cylindrical parts. Based on ABAQUS finite element software, this paper analyses the spin forming of magnesium alloy cylindrical parts, and obtains the influence of key parameters such as mandrel speed, feed rate, thinning rate, roller radius and spinning temperature on the spinning process. The spinning test of AZ31 magnesium alloy long cylindrical parts was carried out, and the test results were consistent with the simulation results. Numerical simulation and experimental verification provide the basis for the development of magnesium alloy spinning process.

Keywords: Magnesium Alloy, Spinning, Finite Element Simulation

1. Introduction
Magnesium alloy is a new green environmental protection structural material in the 21st century, which has the advantages of high specific strength and good specific rigidity. [1-3] At present, the application of magnesium alloy is mainly cast magnesium alloy, but the wrought magnesium alloy can obtain better performance.[4-6] Due to the close-packed hexagonal structure of magnesium alloy, the sliding system is few at low-temperature, and the magnesium alloy is not easy to form. [7, 8] Therefore, the control of forming process parameters becomes a key factor in the formation of magnesium alloy. In the past, the forming process of magnesium alloy thin-walled long cylindrical parts were relatively backward, but with the increasing application of magnesium alloy products, the power spinning of cylindrical parts became the main method for forming such parts. The power spinning (generally called flow spinning) of the cylindrical part is a typical partial loading, point-by-point deformation forming process, which has the advantages of labor saving, material saving and flexibility. [9, 10] Power Spinning is a metal near-net forming method that can form thin-walled, high-precision cylindrical parts. The large length to diameter ratio magnesium alloy cylindrical parts can be applied to many fields such as aviation, aerospace, weapons, and civilian use. [11, 12]
2. Model Establishment and Parameter Selection

2.1. Models and Meshing
The model was established in the ABAQUS software directly. The established finite element model is shown in Fig.1. The figure shows a material with an inner diameter of 240 mm and a wall thickness of 12 mm. The forming is used for power spinning with two rollers. The blank is a three-dimensional deformable solid, and the blank is meshed by an eight-node linear brick, reduced integration, hourglass control unit (C3D8R); the rollers and the mandrel are three-dimensional discrete rigid shells, and the mesh type is a four-node three-dimensional bilinear rigid quadrilateral (R3D4).

2.2. Material Model
The AZ31 magnesium alloy blank was selected for the simulation test. The mechanical properties of the alloy were shown in Table 1. The true stress-true strain relationship curve of the magnesium alloy compression test at strain rate of 0.1 s⁻¹ is shown in Fig. 2[10].

| Parameter | symbol | unit | value |
|-----------|--------|------|-------|
| Feed rate | \( f \) | mm/r | 0.25, 0.5, 1, 1.5, 3 |
| Wall thickness thinning rate | \( \varphi_f \) | % | 12.5, 16.7, 20.8, 25, 29.2 |
| Spinning temperature | \( T \) | °C | 250, 300, 350, 400 |
| The working radius of roller | \( r_p \) | mm | 6, 10, 15 |
| Mandrel speed | \( n \) | r/min | 240, 120, 60, 40, 20 |

2.3. Process Parameters
There are many process parameters affecting the spinning forming of magnesium alloy cylindrical parts, including feed rate, wall thickness reduction rate, spinning temperature, mandrel speed and the working radius of roller. The process parameter values are shown in Table 2.

![Figure 1. Finite element model](image1.png)

![Figure 2. Stress-strain curve at 0.1s⁻¹ strain rate](image2.png)
3. Simulation Result Analysis

3.1. The Influence of Mandrel Speed
The single-roller spinning analyzes the influence of the spindle speed on the formability using a blank with a wall thickness of 12 mm and a length of 100 mm, the reduction is 1 mm, the radius of roller is 10 mm, the material data is input with a stress-strain value of 250 °C. The stress cloud diagram of the mandrel speed $n$ of 120r/min and 180r/min at the feed rate $f=1$ is shown in Fig. 3. It can be seen that the stress distribution is basically the same, and the shape of the mouth after forming is similar.

![Stress Cloud Diagram](image)

**Figure 3.** The stress cloud diagram with the same feed ratio and different spindle speeds

3.2. The Influence of Feed Rate
Ridge height comparison at different feed rates is shown in Figure 4. When the feed rate $f=0.25$, Ridge height has increased sharply before entering the stable spinning, and instability occurs. The feed ratio $f=0.5$–3mm/r is not much different from the spin ridge. When $f=1$mm/r, the ridge height steady changes than other feed rate. Under the same conditions as above, the reference point force of the fixed end of the mandrel changes with time as shown in Figure 5. It can be seen that as the feed rate increases, the force of the roller on the mandrel increases, and the force does not change much when $f \leq 1$mm/r.

![Ridge Height and Force vs Time](image)

**Figure 4.** Effect of feed rate on ridge height.  **Figure 5.** Effect of feed rate on force.

3.3. The Influence of Wall Thickness Thinning Rate
The numerical simulation of the thinning rate of 12.5%, 16.7%, 20.8%, 25%, 29.2%, 32%, and 35% was carried out. The simulation results showed that ridge height was not significantly changed with the thinning rate, when the thinning rate was reached 32% and 35% produced grid distortion, making simulation impossible. The selection of the thinning rate should be selected in conjunction with the wall thickness of the workpieces being less than 30%. The radial force of the mandrel reference point
by the thinning rate changes is shown in Fig. 6. As the thinning rate increases, the maximum value of the radial force increases.

3.4. The Influence of the Working Radius of Roller

The ridge height does not change significantly with the radius of roller during the forming process. Fig. 7 shows the maximum radial force of different round corner radius. It can be seen that the total spin pressure $P$ and the radial spin pressure $P_r$ decrease with the increase of the roller radius. As the radius of roller increases, the ridge and accumulation decrease, resulting in a decrease in the spin pressure. The axial spin pressure $P_z$ takes a maximum value at a radius of 10 mm of roller, and the tangential spin pressure $P_θ$ takes a minimum value.

![Figure 6](image6.png)

**Figure 6.** The radial force by the thinning rate changes.

![Figure 7](image7.png)

**Figure 7.** Roller radius and spin pressure curve.

3.5. The Influence of Spinning Temperature

The influence of spinning temperature on the quality of the workpiece: deformation uniformity deteriorates with increasing temperature.

The effect of spinning temperature on the spinning pressure: As shown in Figure 8, the maximum spin pressure decreases significantly with the increase of the spinning temperature; the deformation temperature does not change much at 300°C and 350°C. However, the increase in temperature has a great influence on the surface quality of workpiece.

In summary, the spinning temperature of 300°C is advantageous for controlling the spinning quality and reducing the spinning pressure.

![Figure 8](image8.png)

**Figure 8.** Maximum spin pressure versus temperature curve.

![Figure 9](image9.png)

**Figure 9.** Sample of spinning & simulation.
4. Test Verification

According to the results of finite element simulation, the spinning process parameters are selected: the radius of roller \(r_f=10\text{mm}\), the mandrel speed 120r/min, the feed rate 1mm/r and the thinning rate less than 30%. Fig.9 is a spinning sample diagram and a simulation diagram. The experimental results are basically consistent with the numerical simulation results.

5. Conclusions

(1) The three-dimensional finite element model of power spinning of AZ31 magnesium alloy cylindrical parts was established. The simulation results reflect the metal flow law. The simulation results are consistent with the test and the model is reliable.

(2) During the spinning process, the mandrel speed has little effect on the forming; as the feed rate and the thinning rate increase, the stress and strain increase, and the maximum stress is always located in the deformation zone where the roller and the blank contact; The temperature increases the stress equivalent stress, the spinning pressure decreases, and the strain increases; as the radius of the working radius of the roller increases, the spinning pressure gradually decreases, and the bell mouth gradually increases.

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