Numerical simulation on spinning manufacturing process based on 2A12 aluminum alloy cylinder part

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Abstract. The 2A12 is a kind of high strength aluminum alloy which is used often in many fields, in this paper, the finite element method (FEM) was used for spinning process simulation of cylinder shell part, different process parameters were designed according to spinning wheel working angle, spinning feed rate. The backward spinning scheme was adopted, through analysis of the spinning manufacturing results, the changing trend of spinning stress was obtained, the influence of different spinning wheel working angle, spinning feed rate on stress, strain and wall thickness was discussed.

1. Introduction

Spinning manufacturing is an advanced forming technology which is developed on the basis of hot forging. It usually spinning the blanks again which is forging. By mounting the metal cylinder blank, the flat blank or the pre-formed blank on the mandrel of a spinning machine and driving the mandrel and blank rotation by the spindle. And the rotary wheel feeds along the bus bar direction of the part. The blank material is squeezed on the mandrel, so that the blank material produced plastic deformation point by point. It can be given various asymmetrical parts which were bus bar shape by spinning. The margin of spinning processing is small, and it belongs to chip-less processing, and the structure of the parts is uniform and the performance is good. Cylinder parts have a wide range of applications in military and civilian products. Therefore, it is necessary to study the spinning process of cylindrical parts and the influence of various spinning process parameters on the spinning forming process. The finite element numerical simulation method can simulate the spinning process effectively [1]. In the literature [2], the DEFOMR software is used to simulate the spinning process of the flywheel, and the stress under different feed rates of the rotary wheel is obtained. The law of the strain and the stress is analyzed. In literature [3], the influence of spinning process parameters on wall thickness and filming degree in spin forming was studied. It was found that the fillet radius of the rotary wheel had the biggest influence on the uniformity of the wall thickness and the filming degree. Reducing the radius of the rounded corners will increase the filming, but will reduce the uniformity of the wall thickness. In [4], the die-free spinning method with auxiliary sticks and how to control the forming process are proposed for the dish-shaped head. The results show that the method can eliminate the wrinkling of the parts after spinning. In [5], the influence of spinning process parameters and load loading changes on the spinning results was studied. The correct selection of spinning process parameters can avoid the instability during spinning. Based on the simulation of spinning process of 2A12 aluminum alloy, this
paper analyzes and summarizes the parameters of the rotary wheel and the influence of the feed rate of the rotary wheel on the spinning process, in order to obtain the influence law of the process parameters such as the working angle of the rotary wheel and the feed rate of the rotary wheel on the spinning result.

2. Spinning simulation parameters

The parts of the spinning process simulation are shown in Figure 1(a), which is a thin-walled cylindrical aluminum alloy part. The spinning process scheme what we adopted is shown in Figure 1(b). Among them, the trajectory of the rotary wheel affects the quality of the spin forming [6-7], and the rotary wheel of this paper adopts the linear feed mode. The material of parts is 2A12 aluminum alloy. The alloy is a high-strength hard aluminum alloy with tensile strength $\sigma_b$ (MPa): 410 and conditional yield strength $\sigma_{0.2}$ (MPa) $\geq$ 265. It is mainly used for processing all kinds of high-load parts and products. It has reasonable composition, good comprehensive performance and high strength. And it is widely used in automobile wheels, aerospace aircraft structural parts and skin parts. Its chemical composition is shown in Table 1. The cylindrical part is spun and formed by the ever-changing local loading of the blank by the rotating wheel, so that the part can get continuously plastically deformed. Whether the plastic deformation process is stable will directly effect the final size, shape accuracy and surface quality of the spinner [8]. Therefore, in the simulation process, in order to ensure that the simulation experiment results are consistent with the practical conditions, the rotating wheel and the core mold are set as rigid bodies, and there is no deformation during the spinning process, ignoring the inertial force and quality attribute of the rotating wheel and the core mold. The spinning simulation process parameters selected in this paper are shown in Table 2.

![Figure 1. Spinning process plan.](image)

| Ingredient | Silicon | Cuprum | Ferric | Manganese | Titanium | Magnesium | Zinc | Nickel | Aluminum |
|------------|---------|--------|--------|-----------|----------|-----------|------|--------|----------|
| Symbol     | Si      | Cu     | Fe     | Mn        | Ti       | Mg        | Zn   | Ni     | Al       |
| Content    | $\leq 0.5$ | 3.8-4.9 | 0-0.5  | 0.3-0.9   | $\leq 0.15$ | 1.2-1.8   | $\leq 0.3$ | $\leq 0.1$ | Allowance |

Table 2. Spinning simulation process parameters.

| Spinning Parameter | Feed Rate $f$ (mm/r) | Attack Angle of Roller $\alpha$ (°) | Spindle Speed $n$ (r/min) | Slab Thickness $t_0$ (mm) |
|--------------------|----------------------|------------------------------------|--------------------------|---------------------------|
| Numerical          | 0.4/0.8/1.2          | 10/20/30                           | 350                      | 7                         |
3. Spinning simulation results

During the spinning process, according to the action of the rotating wheel on the blank, the established rolling pressure is shown in Figure 2, which mainly includes the axial force $F_x$, the radial force $F_y$ and the tangential force $F_q$. $F_i$ is the resultant force of $F_x$ and $F_y$, and the rotational pressure $F_j$ is the resultant force of $F_i$ and $F_q$, that is, the resultant force of the three-direction force $F_x$, $F_y$ and $F_q$.

![Figure 2. Spinning pressure system.](image)

The results of the spinning simulation show that the change trend of the spinning pressure during the spinning process is shown in Figure 3. The stress distribution is shown in Figure 4.

![Figure 3. Spinning pressure curve.](image)

![Figure 4. Stress in the spinning result.](image)

The simulation results show that the maximum stress in the spinning process is located at the contiguous position of the rotating wheel and the blank. At the initial stage of spinning, the spinning pressure increases almost linearly. When the spinning process reaches 50%, the spinning pressure...
basically reaches the peak state. As the spinning process continues, the spinning pressure remains steady. Mainly because during the spinning process, due to the extrusion effect of the rotary wheel on the blank, and the blank material continuously flowing, accumulating and spreading under the action of the rotating wheel, the spinning pressure should overcome the elasticated deformation of the blank material. So there is a change as shown in Figure 3. As the spinning progresses, the radial force of the rotating wheel in the spinning force system is larger, mainly because during the spinning process of the cylindrical part, the material is mainly formed by the removal of the radial margin, the tangential force is relatively small, and the deformation of the material is mainly caused by the radial thinning. Since the spinning process uses reverse spinning, the three-direction stress is compressive stress, and the processed region, the transition region and the processed region are all under pressure.

The strain condition of the part in the spinning result is shown in Figure 5. The strain is distributed more evenly along the circumference of the cylindrical part, and the strain at the contact position between the rotating wheel and the blank is the largest. Since the rotary wheel presses the blank at the contact position, the blank material is deformed along with compression, and at the same time, due to the shearing action, compression deformation occurs in the axial direction and the tangential direction. During the spinning process, the elasticated deformation of the material is overcome, and the initial stage of the spinning pressure is linearly distributed. It is relatively stable at 50%, and the strain is also changing during the spinning process. Due to the spinning pressure generated by the feeding of the rotary wheel, the blank material continuously flows along the feeding direction of the rotary wheel and continues to accumulate in front of the contact area between the rotating wheel and the blank, thereby causing the actual thickness of the spinning blank to continuously change. And the spinning pressure produces fluctuations. At the same time, the equivalent strain will also change accordingly, and the accumulation of blank materials will become more and more serious. Under the action of the rotating wheel, the speed of material flow is slowed down, the work hardening phenomenon occurs, and the deformation is also getting larger and larger. When the material is accumulated to a certain extent, the stress is exerted and released under the action of the rotating wheel, and the deformation is gradually reduced.

![Figure 5. Strain conditions in spinning results.](image-url)
The wall thickness is an important evaluation index of the quality of the parts after spinning. The more uniform the wall thickness, the more uniform the structure of the parts and materials, and the better the quality of the parts. Figure 6 shows the strain distribution in the wall thickness direction. The change of the wall thickness reflects the change of stress and strain during the spinning process. Changes in stress and strain can cause changes in the organization and performance of parts. The wall thickness also reflects the degree of elastically deformed deformation of the blank material, so uneven wall thickness may also result in uneven distribution of internal stress after spinning of the part, and the part is in an unstable state. When subjected to external force during use, the part will be deformed due to changes in internal stress.

Figure 6. Strain distribution in the wall thickness direction.

4. Analysis of the influence of spinning process parameters on spinning results

4.1. Analysis of the influence of the working angle of the rotary wheel

In the spinning scheme, the designed working angles of the rotating wheels are 10°, 20°, and 30° respectively. The simulation results of the three working angles of the rotating wheel show that the stress increases linearly in the initial stage of spinning. When the spinning process is close to 40%, the stress is relatively stable, but the trend of stress strain and wall thickness difference at working angle of 10° and 30° are greater than when the working angle is 20°. The working angle of the rotary wheel mainly affects the contact area between the rotary wheel and the blank and the pressing effect of the rotating wheel on the blank during the spinning process. When the working angle of the rotating wheel is too small, the cross-sectional area of the contact area between the rotating wheel and the blank becomes larger. When the working angle is too large, the actual friction between the rotating wheel and the blank to be processed increases. The tendency of excessive growth of the blank material in front of the rotating wheel is increased, and the blank is prone to wrinkles and bulges. As the stress changes, the strain changes and the wall thickness changes accordingly. Due to the change of stress and strain, the speed of material accumulation, flow and application change. And the elastic deformed deformation and work hardening of the material change accordingly. The influence of the working angle of the rotary wheel on the spinning process is shown in Figure 7.

When the feed rate is increased, the spinning pressure is increased, and the radial force of the spinning is increased significantly. Simulations for the three feed rates of 0.4mm/r, 0.8mm/r and 1.2mm/r show that the greater the feed rate, the greater the stress generated. In the initial stage, the stress and the feed rate are linear. When the spinning pressure is close to 50%, the stress tends to be stable, mainly because as the feed rate increases, the flow, accumulation, and spreading speed of the blank in front of the rotating wheel accelerates, and gradually reaches a peak state. And a change cycle is then completed. The strain distribution corresponds to the stress distribution. In terms of the influence on the wall thickness, the wall thickness at a feed rate of 0.8 mm/r is uniform with respect to 0.4 mm/r and 1.2 mm/r. The main reason is that when the feed rate is too large, the blank material has not yet deformed, and the rotary wheel has been separated from the blank at the position, and the rate
of deformation of the blank is lower than the feed rate of the rotary wheel, so the wall thickness changes greatly. When the feed rate is too small, the total friction between the rotating wheel and the blank in the processing area increases, which affects the deformation of the blank material and the wall thickness changes significantly. The influence of different feed rates on the spinning results is shown in Figure 8.

![Graphs showing the effect of spinning wheel working angle on spinning result](image-url)

**Figure 7.** Effect of the spinning wheel working angle on spinning result.
Figure 8. Effect of the feed rate on spinning result.

5. Spinning Experiment
According to the spinning simulation parameters and the analysis of the spinning simulation results, the spinning process of the 2A12 aluminum alloy cylindrical parts was carried out. The wall thickness variation range was 5.05-5.11 by detecting the parts after spinning. The rotating wheel used and the workpiece after spinning are shown in Figure 9.

Figure 9. Spinning results.
6. Conclusions

(1) In the initial stage of spinning, the spinning pressure almost increases linearly. When the spinning process is close to 50%, the spinning pressure is maximum. As the spinning process continues, the spinning pressure remains stable and gradually decreases.

(2) The change trend of stress strain and wall thickness when the working angle of the rotating wheel is 10° and 30° is greater than that when the angle of the working wheel is 20°.

(3) For the case where the feed rate of the rotary wheel is 0.4 mm/r, 0.8 mm/r, 1.2 mm/r, the greater the feed rate of the rotary wheel, the greater the stress strain, but the feed rate of the rotary wheel the wall thickness at 0.8 mm/r is uniform with respect to 0.4 mm/r and 1.2 mm/r.

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