Numerical simulation of NC spinning manufacturing on tantalum tungsten alloy cylinder part

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Abstract. The tantalum tungsten alloy has excellent mechanical properties which is used extensively in many fields, in this paper, the spinning manufacturing simulation model was built for the tantalum tungsten alloy cylinder part based on finite element method, the spinning process parameters were designed according to the actual working conditions, the stress, strain and the materials flowing behavior during the spinning process were analyzed, the spinning manufacturing results was obtained. Then the influence of spinning wheel working angle, spinning wheel fillet radius, spinning feed rate and thinning rate on equivalent strain was discussed.

1. Introduction

Spinning process, as a non-chip continuous local rotary forming process, belongs to the category of plastic processing [1, 2], and has been widely used in the processing of rotary parts. Compared with the traditional cutting process, the spinning work piece has a series of advantages, such as light weight, high accuracy and good dynamic balance [3]. In addition to the traditional steel and aluminum alloy materials, the spinning technology has been gradually applied to the new metal materials, such as magnesium alloy, titanium alloy and tantalum alloy [4]. The parts machined by spinning method can refine the grain of the material, improve the crystal structure of the material and the related defects [5]. At present, numerical simulation and experimental methods are used to study spinning process parameters [6-7], in document [8], the grey correlation method is used in the study. The optimum technological parameters of spinning are determined by the analysis of the thinning rate, feed ratio, the spinning wheel working angle and the spinning wheel fillet radius as the test factors. In document [9], the influence of feed rate and other parameters on the result of spinning is studied. It is concluded that the increase of feed rate has little influence on the contour when the feed rate is not more than 1mm/r. When the feed rate is greater than 1mm/r, the contour precision will be lost, and the feed rate can be properly raised to control the wall thickness without affecting the contour precision. In document [10], a simulation model of the spinning of parts is set up, the stress and strain in the process of spinning are analyzed. Through the analysis of the wall thickness difference after the spinning, the influence of the feed rate, the spinning wheel fillet radius and the spinning wheel working angle on the wall thickness difference is obtained. In document [11], the influence of spinning process parameters on wall thickness and film thickness is studied. It is concluded that the radius of rotary wheel angle has the
greatest influence on wall thickness uniformity and film thickness, reducing the radius of rotary wheel angle will increase the film thickness, but it will reduce the uniformity of wall thickness.

This paper mainly focuses on the numerical simulation of tantalum tungsten alloy cylindrical workpiece with three wheel offset spinning, analyses the stress and strain of the material in the process of spinning, and analyzes the influence of the parameters.

2. Numerical simulation scheme for spinning process of cylindrical parts

2.1. Spinning process parameters of cylindrical parts

The spinning workpiece is a cylindrical part, the material is tantalum tungsten alloy (Ta-2.5W), and the material property parameters are shown in Table 1. Compared with the processed cylindrical parts, the deformation of the rotary wheel and the core die is negligible in the process of spinning. Therefore, the rotary wheel and the core die are set as non deformation analytical rigid bodies during the spinning process. The technological parameters selected for cylinder spinning are shown in Table 2.

| Table 1. Ta-2.5W Material properties. |
|--------------------------------------|
| Modulus of elasticity $E$ (GPa) | Poisson ratio $\mu$ | Density $\rho$ (g/mm\(^3\)) | Tensile strength $\sigma_b$ (MPa) | Yield strength $\sigma_p$ (MPa) | Elongation (%) |
| 179 | 0.35 | 16.7 | $\geq$276 | $\geq$152 | 20 |

| Table 2. Spinning process parameters of cylindrical parts. |
|-------------------------------------------------------------|
| Outer diameter of billet (mm) | $d$ | 102 |
| Initial thickness of blank (mm) | $t_0$ | 10 |
| Spindle speed (r/min) | $n$ | 150 |
| Wheel exit angle ($^\circ$) | $\alpha_0$ | 10 |
| Roller thickness (mm) | $d_0$ | 35 |
| Rotary wheel diameter (mm) | $D_\rho$ | 200 |
| Wheel offset (mm) | $C$ | 6 |
| Rotary wheel working angle ($^\circ$) | $\alpha_\rho$ | 10,15,20,35 |
| Circle radius of rotary wheel (mm) | $y_\rho$ | 6,8,10,12 |
| Thinning rate of wall thickness (%) | $\psi_t$ | 20,25,30,35 |
| Feed rate (mm/r) | $V_f$ | 0.8,1.2,1.5,1.8 |

2.2. Simulation model of rotary pressure of cylindrical parts

As shown in Figure 1(a), the workpiece's spinning model is built according to actual spinning condition. The workpiece is fixed on the core mold and rotates with the core mold synchronously. At the same time, the workpiece must be pushed along its axial direction.

In the process of finite element analysis, in order to ensure the consistency with the actual spinning conditions, assuming that the workpiece is fixed with the core mold, the spinning wheel moves along
the axial and rotation of the workpiece's axis and the surface of the blank. The space position of the three revolving wheels, as shown in Figure 1(b).

Figure 1. Spinning scheme of cylindrical parts and spatial position: (a) Spinning scheme; (b) Position relation between rotating wheels.

3. Analysis of simulation results of cylindrical parts spinning
The equivalent stress and strain in the forming process of cylinder parts are shown in Figure 2. It can be seen that the maximum equivalent stress locates in the forming zone at the contact area of the outer surface. With the continuous rotation of the spinning wheel, the equivalent stress increases continuously, and the regions of the maximum effect force increase constantly. The equivalent stress produced in the outer surface of the machined area is different, and the equivalent stress on the outer surface is large, the equivalent stress on the inner surface is small, surface material uplift leads to the increase of the equivalent stress during spinning process.

Figure 2. Equivalent stress strain distribution cloud map: (a) Stress condition of forming 50%; (b) Stress condition of forming 100%; (c) strain condition when forming 50%; (d) strain condition when forming 100%.
The equivalent strain becomes more and more large during the forming process. At the initial stage of forming, the maximum value of the equivalent strain is produced in the ring area that contact the outer surface of the rotary wheel. The distribution is more uniform. The equal effect produced by the outer blank is bigger than the inner blank. With the continuation of the spinning process, the maximum area of the equivalent strain occurs. Changing and expanding, forming 100% almost covers the outer surface of the whole workpiece.

In order to analyze the stress and strain distribution in the contact area of the blank further, spinning wheel and the flow of the metal in the contact area between spinning wheel and workpiece, the distribution of the axial stress and strain on the outer surface are obtained, as shown in Figure 3 and Figure 4.

![Figure 3](image1)

Figure 3. Stress and strain clouds on the outer surface of the contact area: (a) Radial stress; (b) Tangential stress; (c) Axial stress; (d) Equivalent stress; (e) Radial strain; (f) Tangential strain; (g) Axial strain; (h) Equivalent strain.

From Figure 3 and Figure 4, it can be seen that the three direction stress (radial, axial and tangential) in the contact area between the spinning wheel and the workpiece is negative, and the material bears the pressure stress and the radial stress are large, which indicates that the workpiece is in compression state during the spinning process, but in tension state in cutting direction. The metal blank in front of the contact area is in radial tension state and is in compression state along the axial direction. With the continuous rotation of the spinning pressure, the blank material accumulates and accumulates continuously under the action of the rotary wheel. The blank material ahead of the spinning wheel produces a wrinkle, and the tensile or compression of the cylindrical blank in the radial direction causes the workpiece to expand in different degree. In diameter or shrinkage, when the elongation of metal is greater than the amount of compression, the expansion diameter is produced, and on the contrary, it shows the shrinkage diameter. From the figure, it can be seen that the blank material in front of the spinning wheel forward is under compression strain, while the rear blank material of the rotating wheel is under tensile strain, the workpiece produces axial elongation.

The shrinkage deformation of the blank in the contact area of the rotary wheel and the workpiece is different, which causes the blank material to flow along the tangential direction. It can be seen from the migration of the workpiece mesh in the finite element model, which leads to the deflection of the blank material busbar after the spinning. The adjacent parts between the rotating wheel and the workpiece have certain constraints on the deformation and flow of the material. The flow of the blank
material in the direct-action area will be hindered by the adjacent area of the blank material, thus making the front and back side materials of the spinning wheel and the workpiece produce a certain axial strain.

![Image](image_url)

**Figure 4.** Image of stress and strain distribution in axial section: (a) Radial stress; (b) Tangential stress; (c) Axial stress; (d) Equivalent stress; (e) Radial strain; (f) Tangential strain; (g) Axial strain; (h) Equivalent strain.

4. Discussion

For obtaining the blank material flow and deformation feature, take the point P on the surface as example to demonstrate the deformation on every second during the spinning process, as shown in Figure 5.

At the beginning of spinning process, no change happened with point P, when t=30s, the contact area between spinning wheel and workpiece closes to P, the material wrinkle was generated, and the radial movement generated also, when t=44s, the wrinkle value was maximum, when t=56s, the spinning wheel contact with P, under the influence of spinning wheel, the P shrink toward the cylinder part center, the material became thin, when t=85s, all the three wheels passed through P, the material thickness was minimum. Along the thickness direction, choose five paths in axial, and the different material elongation could be concluded in Figure 6.

The stress increases while increases the spinning wheel working angle, the contact area between spinning wheel and blank decreases, and the blank material has good flow character, but the material in front of spinning wheel is easy to accumulate, and certain wrinkle should be generated, meanwhile, the internal diameter expanding decreases gradually, the wall-thickness difference increases more and more, equivalent strain decreases. While increases spinning fillet radius, the contact area increases
between spinning wheel and workpiece per unit time, the blank material flow volume increases, the material accumulates in front of spinning wheel along spinning direction, the internal diameter expanding increases gradually, the wall-thickness difference decreases gradually, during the forming process, the equivalent strain increases gradually also.

While increases spinning feed rate, the material accumulates easily in front of spinning wheel, the forming quality is not good, both the internal diameter expanding and wall-thickness difference increase, the equivalent strain increases gradually. While increases thinning rate, the material wrinkle generates obviously in front of spinning wheel, the material deformation becomes difficult, but the internal diameter expanding and wall-thickness difference change obviously, the instability phenomenon of workpiece appears easily, the deformation of blank material becomes nonuniform, the equivalent strain changes obviously. The analysis results as shown in Figure 7.

![Figure 5](image1)

Figure 5. Changing situation of P: (a) Original position P; (b) t=30s; (c) t=44s; (d) t=56s; (e) t=85s.

![Figure 6](image2)

Figure 6. Material elongation condition after spinning.
Figure 7. Influence of spinning parameters on equivalent strain: (a) the influence of working angle; (b) the influence of wheel fillet radius; (c) the influence of feed rate; (d) the influence of thinning rate.

5. Conclusions

(1) The spinning process of cylindrical parts is a local plastic forming process, and the contact area between the blank material and the rotary wheel shows a state of three-dimensional compressive stress.

(2) In the transition region of spinning process, the blank material produces displacement along axial, radial and tangential direction, and the axial displacement is the largest, which leads to the axial elongation of the blank.

(3) The equivalent strain decreases while increases the spinning wheel working angle, but increases while increases spinning wheel fillet radius, feed rate and thinning rate.

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