Study on Spinning Process Parameters of the Copper Bushing by Tribological Properties and Physical Testing

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Abstract. The bushing is a kind of ring sleeve which acts as a liner outside the mechanical parts, which needs good strength, hardness and fatigue resistance. In this paper, the copper bushing was prepared by spinning forming method, and the process parameters of spinning were explored. According to the results of material thermal simulation and test, the conclusion is that the spinning process of copper bushing needs to be carried out in two passes by reverse spinning method. The thinning rate is 30% and 25% respectively. The gap between the mandrel and the roller is 10mm, the feed ratio is 1mm/r, and the spinning temperature is 250℃.

Keywords: Copper bushing, Spinning, Process parameters.

1. Introduction

The bushing is a kind of ring sleeve which acts as a liner outside the mechanical parts. It can reduce the wear between the bearing and the shaft seat, and avoid the increase of the clearance between the shaft and the hole. The bushing needs to withstand vibration, friction and corrosion in various harsh working environments to protect the wrapped parts. Therefore, bushing material needs to have good hardness, strength and fatigue resistance [1-3].

Copper alloy is one of the main materials of bushing, also known as copper bushing. The process of semi-continuous casting with hot extrusion and cold drawing annealing is adopted to prepare the silicon brass bushings by Wieland. At present, the mass production has been realized and the market share has reached more than 80%. The tensile strength at room temperature is more than 600MPa, the yield strength is more than 540MPa, the elongation after fracture is more than 8%, and the hardness is more than 180HB.

The copper bushing at home is mainly made of copper alloy such as tin bronze and phosphor bronze, which is expensive. The forming method is solid-bar-machining or forging-machining. The material utilization rate is low, and the energy consumption is high. Researchers in North University of China, Shanghai Jiao Tong University and other units developed it by the process of extruding tin bronze rod into tube and spinning. The tensile strength is about 540MPa, while the hardness is about 170HB at room temperature, which is far behind that of imported ones.

Spinning is an advanced plastic forming process, which integrates the process characteristics of drawing, forging, extrusion and rolling. It can achieve the effect of work hardening through grain
refinement, and effectively improve the hardness, strength, anti-softening and other properties of cylindrical parts at the same time. It also has high material utilization rate and simple operation [4-6]. In this paper, the copper bushing was prepared by spinning, and the spinning process parameters were explored to lay the foundation for breaking the performance of copper bushings.

2. Test methods

2.1. Test material
Silicon brass CuZn31Si1 is selected as the test material, and the chemical composition is shown in Tab.1.

| Zn   | Si  | Pb  | Fe  | Cu          |
|------|-----|-----|-----|-------------|
| 31.06| 0.935| 0.270| 0.015| Bal.        |

2.2. Bushing preparation
In this experiment, horizontal continuous casting and spinning were used. Firstly, the molten copper was continuously cast horizontally to obtain copper tube billet. Then the copper tube ingot obtained by horizontal continuous casting was used as spinning blank, and the final copper bushing samples were obtained by reverse spinning. In order to reduce the number of spinning process test, the process test scheme was simulated and optimized before preparation, and the test was verified according to the results of simulation and optimization. The optimization of thermal simulation test was carried out on Gleeble 3500 thermal simulation test machine. The sample size was 8mm×12mm. The deformation temperature was 150℃, 200℃ and 250℃. The strain rate was 0.01s⁻¹, 0.1s⁻¹ and 1s⁻¹.

3. Test results and analysis

3.1. Thermal simulation test
Fig.1 shows the true stress-true strain curve of CuZn31Si1 at the same temperature and different strain rates, while the Fig.2 shows the true stress-true strain curve at different temperatures and same strain rate.

Fig 1. True stress-true strain curves of CuZn31Si1 at the same temperature and different strain rates.
Fig 2. True stress-true strain curves of CuZn31Si1 at the different temperatures and same strain rate.

It can be seen from Fig.1 and Fig.2 that when the specimen is heated and compressed, there is an obvious strain strengthening effect. The stress increases with the increase of strain (within a certain range), but there is no obvious yield stage. At the same temperature, with the increase of deformation rate, the true stress increases obviously. The material shows a certain strain rate strengthening effect. At the same strain rate, with the increase of deformation temperature, the peak stress decreases obviously. The material shows a strong temperature softening effect. Temperature is one of the most important factors affecting flow stress. In general at high temperature, the resistance of metal dislocation sliding decreases and new sliding occurs. Meanwhile the metal also recovers and recrystallizes to reduce or eliminate the work hardening caused by plastic deformation, so as to reduce the flow stress. In addition, most of the deformation energy is converted into heat energy during deformation, which also changes the internal temperature and affects the flow stress of the metal.

Therefore, considering the influence of temperature and deformation rate on the true stress, the maximum deformation resistance is different at different temperature. So different spinning temperature should be selected according to different deformation resistance.

3.2. Spinning mode selection
Since the bushing is a cylindrical part, the reverse spinning method can be determined. The process is shown in Fig. 3. In reverse spinning, the material flow direction is opposite to the feed direction of the spinning wheel. So the length of the spinning part can exceed the mandrel. With the increase of the number of bushings that can be cut in to single, the useful section of the spinning part is much longer than the remaining section, and the material utilization rate is improved. However, with the increase of the length of spinning parts, the gravity arm increases. The rotation instability increases, with the straightness and cylindricity of spinning parts decrease. Therefore, it is necessary to reasonably design the length of the spinning part, which is to select the number of pieces that can be cut bushings into a single spinning part.

Fig 3. Schematic diagram of reverse rotation.
3.3. Matching test of thinning rate and spinning pass

According to the material types and performance requirements of parts, the total reduction rate of spinning deformation, the number of spinning passes and the wall thickness reduction rate of each pass are determined by the spinnability and cold deformation hardening characteristics of the materials the thinning rate of cylindrical spinning parts is generally less than 40%. The matching scheme of thinning rate and spinning pass is shown in Tab.2.

| Scheme   | Passes  | Thinning rate | Yield rate | Processing efficiency |
|----------|---------|---------------|------------|-----------------------|
| Scheme 1 | Passes 1| 40%           | 75%        | 20 piece/h            |
| Scheme 2 | Passes 1| 30%           | 95%        | 10 piece/h            |
|          | Passes 2| 25%           |            |                       |

Fig 4. The sample photos after spinning.

The samples after spinning was shown in Fig.4. The sample for Scheme 1 has large thinning size, easy surface cracking and low yield, while that for scheme 2 has good surface quality and high yield. Therefore according to the above experimental analysis, it is determined that the thinning rate is 30% and 25% respectively after two passes of spinning.

3.4. Determination of processing parameters

The clearance between the mandrel and the roller, the feed ratio and the processing temperature are the main control parameters in the spinning process, which have a direct impact on the mechanical properties, quality and accuracy of the parts.

3.4.1. Orthogonal test of processing parameters

For the reverse spinning process of silicon brass cylindrical parts, there are few reference materials in the process parameter control, so it is necessary to carry out some experiments. In this test, three levels of the above three factors are selected respectively, and orthogonal test table L9 (3^4) is used. The factor-level table is shown in Tab.3. The Leeb hardness of the spinning parts is taken as the evaluation index, and orthogonal test Tab.4 is obtained.

| Factor Level | A (Clearance) | B (Feed ratio) | C (Temperature) |
|--------------|---------------|----------------|-----------------|
| 1            | 12            | 0.5            | 150             |
| 2            | 10            | 1.0            | 200             |
| 3            | 8             | 1.5            | 250             |
Tab 4. Orthogonal test table $L_9(3^4)$.

| Factor Test | A (Clearance) | B (Feed ratio) | C (Temperature) | Leeb hardness |
|-------------|---------------|----------------|-----------------|---------------|
| 1           | 1             | 1              | 1               | 586           |
| 2           | 1             | 2              | 2               | 605           |
| 3           | 1             | 3              | 3               | 597           |
| 4           | 2             | 1              | 2               | 620           |
| 5           | 2             | 2              | 3               | 637           |
| 6           | 2             | 3              | 1               | 630           |
| 7           | 3             | 1              | 3               | 609           |
| 8           | 3             | 2              | 1               | 611           |
| 9           | 3             | 3              | 2               | 615           |
| $T_1$       | 1788          | 1815           | 1827            |               |
| $T_2$       | 1887          | 1853           | 1840            |               |
| $T_3$       | 1835          | 1842           | 1843            |               |
| $T_1$       | 596.00        | 605.00         | 609.00          |               |
| $T_2$       | 629.00        | 617.67         | 613.33          |               |
| $T_3$       | 611.67        | 614.00         | 614.33          |               |
| Range       | 33.00         | 12.67          | 5.33            |               |

3.4.2. Analysis of orthogonal test results. It can be seen from the Tab.4 that the maximum value of Leeb hardness is 637 obtained by adopting scheme A2B2C3. So A2B2C3 is initially determined as the best scheme.

Make a trend chart of the influencing factors of Leeb hardness, as shown in Fig.5. From the range analysis, among the three factors, the importance of hardness is A>B>C. The range analysis method is used to analyze from the figure, and the scheme A2B2C3 contains the best level of each factor, which is the optimal combination.

![Fig 5. Trend chart of orthogonal test for processing parameters.](image)

4. Conclusions
According to the results of material thermal simulation and test, the conclusion is that the spinning process of copper bushing needs to be carried out in two passes by reverse spinning method. The thinning rate is 30% and 25% respectively. The gap between the mandrel and the roller is 10mm, the feed ratio is 1mm/r, and the spinning temperature is 250℃.
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