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RESEARCH ON INTEGRATED FORMING PROCESS OF THREE-ROLL REDUCING AND THICKENING OF NECKING SECTION FOR THIN-WALLED TUBE OF ALUMINUM ALLOY 2A12

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Aircraft joystick pipe is the key part of aircraft hard control system. In this paper, a hollow necking rod pipe made of aluminum alloy 2A12 is taken as the research object. The tapered roller with extrusion cone on one side of the roller surface is designed. Simufact.Forming14.0 was used to analyze. It was found that the radial rolling force at the end of the thickening section in the second pass increased sharply. At this time, the retaining part inhibited the axial extension of the metal and realized the accumulation in the thickness direction. The thickening rate and effect were favorable at 120 rpm, which provide a theoretical basis to realize integrated forming of aeronautical thin-walled aluminum alloy tube.

Keywords: aluminum alloy 2A12, three-roll forming, thin-walled pipe, thickening.

INTRODUCTION

The joystick pipe is an important component of an aircraft, which is mainly used as the control component of the aircraft hard control system and the transmission component of the auxiliary power system. It's a typical long-axis thin-walled tube, which is generally made of aluminum alloy, titanium alloy, and so on.

In recent years, domestic and foreign scholars have carried out corresponding research on the processing methods of aircraft joystick pipe parts. Li et al. proposed the stamping and compression forming process for rear support part, which effectively improved the production efficiency and reduced the machining process [1]. Based on the shrinkage process of industrial pure titanium pipe, Zhang et al. studied the process methods of shrinkage and rotary forging forming of shaped pipe, and analyzed the influence of shrinkage mode and process design on the quality [2]. Xia et.al innovated the three-roll skew rolling process to realize the reduction and thickening of thin-walled tube [3]. Luo et al. studied the spinning forming of aviation large-scale thin-walled parts, and carried out the experimental analyze on it by using the composite spinning process of counter-roll spinning and multi-neck spinning, and obtained the optimal process parameters [4].

However, the existing reports in China and abroad mainly studied the process method of tube shrinkage forming, and there were few studies on the thickening of tube end. The research on three-roll skew rolling process mainly focuses on the forming of stepped shafts and the reduction forming of seamless steel pipe.

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FINITE ELEMENT MODEL

Target forming part

The size of an aviation thin-walled tube with a length of L after rolling is shown in Figure 1. The three-roll skew rolling is used to reduce the diameter to 16 mm. Where, D and s are the initial outer diameter and initial wall thickness. d_1 and d_2 are the outer and inner diameter of the necking section. L_1 and L_2 are the length of thickening section and reducing section. The original outer diameter and wall thickness are selected according to the stress and length of the rod, and the length of the pipe body should not be too long. In this paper, a cylindrical thin-walled tubular billet with an initial outer diameter of 32 mm and an initial wall thickness of 1,5 mm is adopted. Due to the symmetry at both ends of the rod, in order to save the finite element simulation time and forming accuracy, half pipe is taken for simulation.

Generally, the strength of the thickening segment is calculated according to the thread major diameter in the thickening section. The cross-sectional area of the nozzle section should be as equal as possible to the cross-sectional area of the pipe body [1], namely:

$$\frac{\pi}{4}\left(d_1^{\,2}-d_2^{\,2}\right)=\frac{\pi}{4}\left[D^2-\left(D-\mathrm{s}\right)^2\right] \tag{1}$$

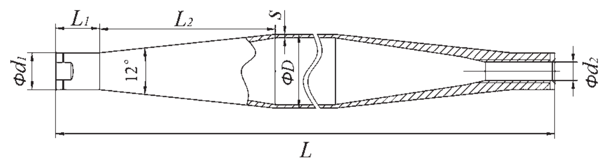


Figure 1 Hollow rod pipe

The outer diameter of the pipe:

$$d_1 = \sqrt{d_2^{\,2} + s\left(s - 2D\right)} \qquad (2)$$

Assembly model and roller design

Three roll skew rolling technology is a process mainly used for processing shaft parts and pipe fittings. The established finite element model includes pipe fittings, rolls and clamping-retaining device, as shown in Figure 2. The three rolls are uniformly distributed around the center line at 120 °, rotating in the same direction while compressing in the radial direction. Due to the existence of the deflection angle between the axis of roll and pipe, the friction drives the hollow tube to rotate passively in the opposite direction and advance in a spiral state. By controlling the radial feed of the roll, hollow tubes with different end diameters can be formed, which broadens the forming range of the rolled piece. A fixture with retaining and clamping part is arranged. Both of them simultaneously clamp and locate the pipe, so that the pipe is not easy to move during processing and the axial elongation of the pipe is suppressed. The contact between the tube and the fixture is set as bonding, so the fixture drives the tube to move axially synchronously. The friction coefficient between the billet and the three rolls is 0,95, and the billet temperature and the ambient temperature are set to 20 °.

The Simufact.Forming14.0 software was used for simulation. The conical roll with extrusion cone on one side of the surface was designed to compress the hollow tube, so as to promote the axial flow of materials on the hollow tube and the radial accumulation of the end, thereby improving the thickening effect and forming quality. The roll size is shown in Figure 3, where D_1 and D_2 are the big diameter and small diameter of the roll, α_1 and α_2 are the plane angle and cone angle, *h* and *r* are the height of the shaping area and the radius of the cone. The cone angle and cone diameter of the roller can be adjusted appropriately to achieve different thickening effects.

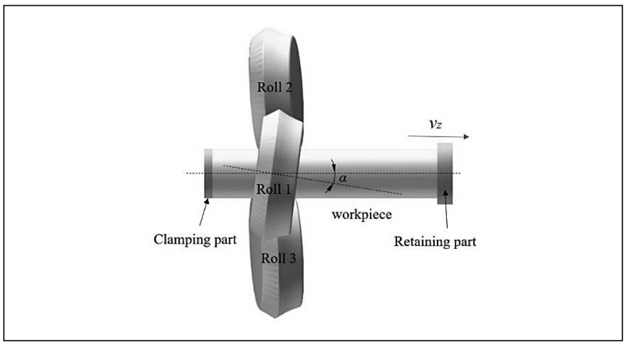


Figure 2 Finite element model

Figure 3 Design of roll shape

Material model

2A12 aluminum alloy has the characteristics of low density and high strength, so it has become a common material in aviation, aerospace and military industries. Especially in the ultra-high velocity impact protection of space debris, 2A12 aluminum alloy is a common material for the protective screen. 2A12 aluminum alloy with low density and high strength is selected as the pipe material in this paper. The expression of Jackson-Cook model is [5]:

$$\sigma = [370,4 + 1798,7\varepsilon^{0,73}][1 + 0,0128\text{In}\dot{\varepsilon}^{*}][1 - T^{*1,53}] \qquad (3)$$

$$T^* = (T - T_r) / (T_\text{m} - T_r) \qquad (4)$$

where, e is equivalent plastic strain, $\dot{\varepsilon}^*$ is the relative equivalent plastic strain rate, $\dot{\varepsilon}^* = \dot{\varepsilon} / \dot{\varepsilon}_0$; the reference strain rate $\dot{\varepsilon}_0$ is the strain rate in the quasi-static experiment ; and T^* is dimensionless.

ANALYSIS OF FORMING PROCESS

The simulation process parameters are shown in Table 1. The forming process is mainly divided into three stages: equal-diameter stage, reducing-diameter stage and thickening stage. This simulation uses two-pass forming, the two-passes unilateral reduction are 4 mm and 8 mm respectively, the second-pass forming process pipe section is shown in Figure 4.

There is almost no plastic deformation in equal diameter section. In the reducing section, the boundary conditions are applied by setting the displacement, and the axial movement is carried out at a certain speed. When the forming process reaches 40 % - 60 %, mate-

Table 1 **Simulation parameters**

α /°	5	D_1/mm	86
v /r·min^{-1}	90	D_2/mm	72
α_1 /°	35	r/mm	50
α_2 /°	30	d_1/mm	16

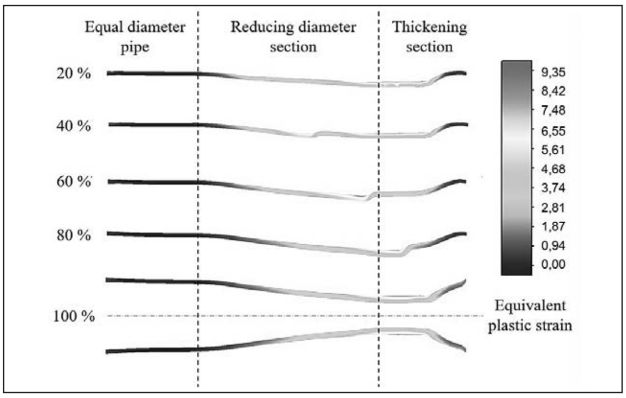


Figure 4 The second pass forming process of three-roll skew rolling

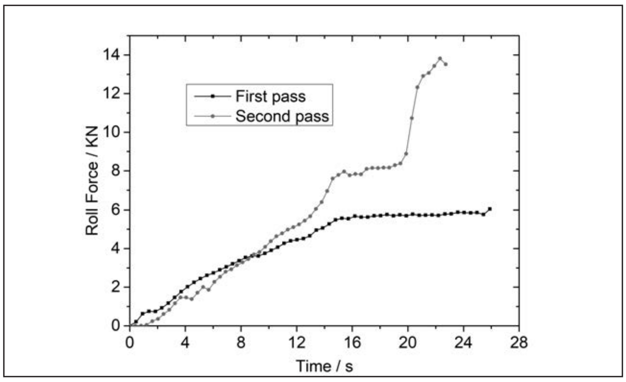


Figure 5 Radial rolling force of two rolling passes

rial shows the trend of axial protrusion. In the thickening section, the roll is no longer reduced in radial compression, and the axial movement speed of the fixture becomes slower. The pipe rotates backward under the friction of the roller and moves axially with the chuck. Since the end of the pipe is equipped with a retaining part, the axial flow of the metal and the axial extension of the pipe are hindered. At this time, the equivalent plastic strain penetrates into the inner wall of the pipe, and the metal mainly flows in the radial direction. The axial no longer presents the bulge phenomenon, and the end wall thickness increases.

The radial rolling force of two passes was compared, as shown in Figure 5. In the reducing section, the rolling force showed a uniform growth trend, and the roller was compressed with equal speed radial feed. In the thickening section, the change trend of rolling force in the first pass is gradually stable, but increases sharply after the second pass enters the thickening section about 5 s. This is because the reduction rate of the first pass is small. However, the reduction rate of the second pass reached 50 %. After rolling for 20 s, the stopper at the end of the pipe inhibited the axial extension of the metal, accelerated the metal accumulation in the thickness direction, and made the rolling force rise sharply at this stage, which was also the main deformation stage to achieve thickening.

EFFECTS OF ROLL SPEED ON THICKNESS OF NECKING END

The necking end of the traditional rod pipe needs to be threaded and then connected with the rod end bearing to form a tie rod assembly. The wall thickness and uniformity of the wall thickness at the necking end have certain technical requirements corresponding to different use occasions. The change of process parameters has direct impact on the forming quality and subsequent processing. The working principle of three-roll skew rolling is that three co-rotating rolls drive the rolling piece to rotate in the opposite direction, so the roll speed has an important influence on the wall thickness distribution and uniformity. Figure 6 shows the same process parameters and different roll speeds. It can be seen that the thickening effect of the roll rotation speed is better when the rotation speed is high, and the calculation of the wall thickness uniformity requires the introduction of evaluation indicators.

In this paper, four equal roll speeds are set up, which are 30 rpm, 60 rpm, 90 rpm and 120 rpm respectively. 35, and 15 wall thickness measuring points are taken equidistantly along the reducing section and thickening section respectively. Figure 7 shows the variation of wall thickness distribution under different roll speeds.

The change trend of the first pass is basically the same. When the reducing section is just entered, the wall thickness is maintained near the initial wall thickness. With the increase of the reduction, the wall thickness of the reducing section increases, and the maximum thickening rate does not exceed 1.5. In the second pass, it can be seen that the wall thickness changes abruptly in the middle section at 60 rpm, the wall thickness changes more evenly in the reducing section at 90 rpm and 120 rpm, and the end wall thickness is the largest at 120 rpm.

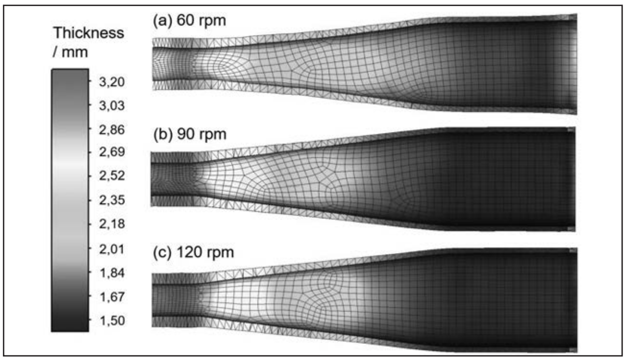
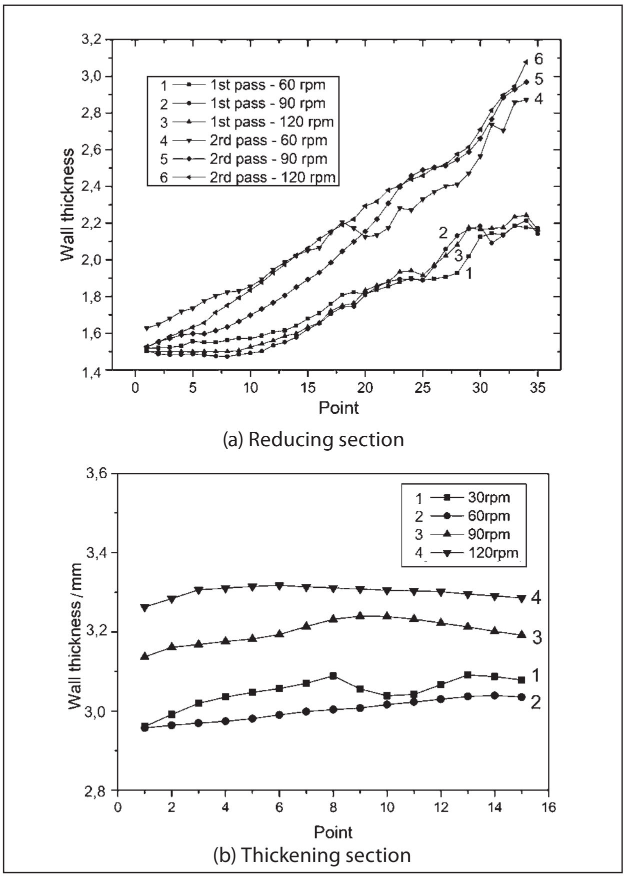


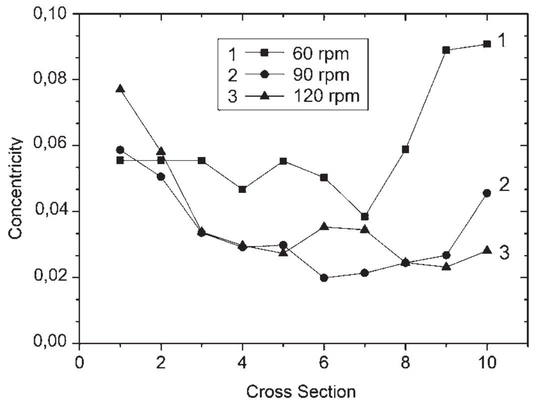
Figure 6 All thickness distribution under different roll rotational speed



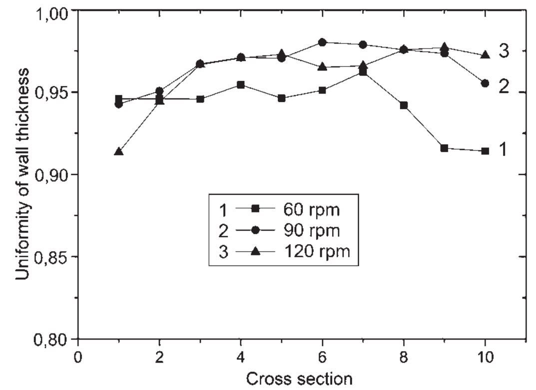
(a) Reducing section

(b) Thickening section

Figure 7 Variation of wall thickness



(a) Concentricity



(b) Uniformity of wall thickness

Figure 8 Concentricity and wall thickness uniformity of thickening section

The wall thickness distribution of the thickening section is shown in Figure. Thickening effect is most ideal at 120 rpm, and thickening rate reaches 2.2.

Due to the material backflow phenomenon, the uneven distribution of cross-section wall thickness in the thickening section will not only affect the finish machining of the end of the pipe, but also lead to the scrap of the rod pipe. In the thickening section, 10 sections are evenly selected as the research object. The concentricity is used as the evaluation index of wall thickness uniformity. where, *s* is the wall thickness between the inner and outer circles, *X, Y, Z* are the cross-section point coordinates. s_{max} and s_{min} are the maximum and minimum wall thickness.

Average wall thickness:

$$s_{ave} = \frac{1}{60}\sum_{n=1}^{60} s_i \tag{5}$$

Concentricity:

$$\delta = \frac{s_{\max} - s_{\min}}{\mathrm{s}_{\min}} \tag{6}$$

Wall thickness uniformity:

$$\gamma = (1 - \frac{s_{\max} - s_{\min}}{s_{ave}}) \times 100\% \tag{7}$$

It can be seen from Figure 8 that when the roll speed is 60 rpm, the wall thickness uniformity and concentricity change greatly. The change trend of 90 rpm and 120 rpm is similar. In the first section closest to the initial thickening section, the wall thickness uniformity of 120 rpm is slightly lower. Considering the wall thickness of the necking section, the wall thickness forming effect at 120 rpm is favorable.

CONCLUSIONS

The conical roll with extrusion cone on one side of the roll surface is designed, which can promote the axial flow of the hollow pipe material and the radial accumulation of the end, indicating that the synchronous short-process forming process of the three-roll diameter reduction and the thickening of the aviation thin-walled pipe is feasible.

The radial rolling force at the end of the thickening section of the second pass increased sharply, and the retaining part inhibits the axial extension of the metal and accelerates the accumulation in the thickness direction. The thickening rate and effect were favorable at 120 rpm, and it can be improved by optimizing the speed ratio and process parameters.

This study breaks the technical constraints of multi-step process forming of aviation thin-walled aluminum alloy tube, and innovates the integrated forming method of reducing diameter and thickening, which provides a theoretical basis for realizing the high-quality forming of aviation thin-walled aluminum alloy tube.

Acknowledgments

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Note: The responsible translator for English language is Y.X. Xia, Ningbo, China.