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Research Article

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Research on the forward slip of rolling-extrusion forming for variable wall thickness cylinder parts

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ABSTRACT

In the production of variable wall thickness cylinder parts，there are many questions of low material utilization process, long machining man-hour, high production costs. In order to solve these problems, a new method of rolling-extrusion process was put forward. In this process material is formed by means of three passive rotational tools. The charge is provided by means of a pusher pushing the billet in a working space between the profiled rolls. In this paper, the authors focused on determining the forward slip of rolling-extrusion process to get the precision size control of this part.Deform-3D were used to verify the forward slip model and feasibility of the processes. The production test showed that the parts can be produced accurately using rolling-extrusion technique and the material utilization was increased by 19%.

Key words: variable wall thickness cylinder; rolling-extrusion; forward slip model

INTRODUCTION

Variable wall thickness cylinder parts (Fig.1) are widely used in the production of projectile bodies, and the production is very big. The traditional methods of manufacturing use "stamping - stretch" process to form a straight wall of the cylinder, and then cut out different wall thickness [1]. The deficiencies of this method is as follows: 1) low material utilization;2) big consumption of cutting tools;3) high production costs. At present, the newer solutions concern spin extrusion [2, 3]. But the productivity is very low, and the cylinder is difficult to stripping from the punch.

To address these issues, in this work, the rolling-extrusion technique was presented. In this process a cylinder part is pushed into a working space between three profiled rolls by a punch. At the meantime, the rolls will rotate and compress the metal under the action of friction. Then the billet will get axial elongation and decrease of wall thickness. However, it is very difficult to control the axial elongation, because of the forward slip.

In this work, the authors focused on determining the forward slip of rolling-extrusion process to get the precision size control of this part, and Deform-3D were used to verify the forward slip model and feasibility of the processes. At last , the specimen will be manufactured.

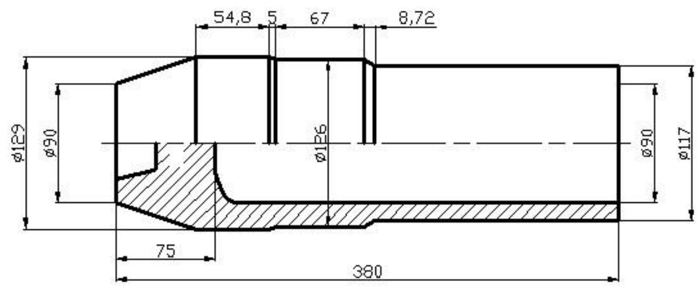


Fig.1 Parts diagram

2 Model building of forward slip

2.1 forward slip of groove vertex determining

As shown in Fig.2, forward slip can be obtained using Eqn. (1):

$$s = (v_1 - v_\gamma \cos\gamma) / v_\gamma \cos\gamma \times 100\% \tag{1}$$

Where v_1 is roll linear speed ; γ is the neutral angle ; v_γ is plate speed corresponding to the neutral angle.

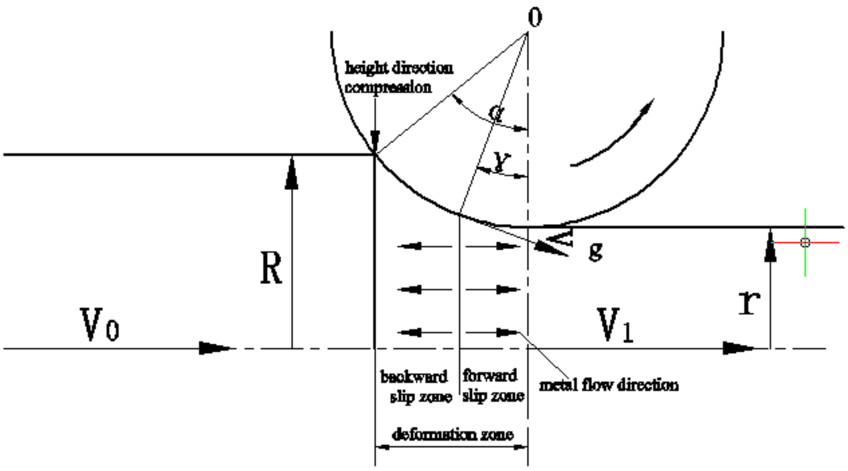


Fig.2 metal flow in deformation

According to the mass flow per second is constant，then

$$\pi r^2 v_1 = \pi {r_\gamma}^2 v_\gamma \tag{2}$$

For Fig.2 there are:

$$r_\gamma = r + R_d\left(1 - \cos\alpha\right) \tag{3}$$

$$v_1 / v_\gamma = \left(1 + R_d\left(1 - \cos\gamma\right)/r\right)^2 \tag{4}$$

$$s = \left(1 + R_d\left(1 - \cos\gamma\right)/r\right)^2 \cos\gamma - 1 \tag{5}$$

Where R_d is the roll radius; α is biting angle

Assuming pressure p is uniformly distributed on the arc of contact unit; the metal flow resistance is equal on both sides of neutral surface [6], then

$$pR_d \int_\gamma^\alpha (\rho\cos\phi - \sin\phi)d\phi = pR_d \int_0^\gamma (\rho\cos\theta + \sin\theta)d\theta \tag{6}$$

The value of γ and α is very small

$$\sin\phi \approx \phi, \sin\theta \approx \theta, \cos\phi \approx 1, \cos\phi \approx 1 \quad (7)$$

$$\gamma = \alpha/2(1-\alpha/2\rho) \quad (8)$$

2.2 **forward slip of the whole groove determining**

Forward slip value and neutral Angle are changing in the direction of the width of the groove. Therefore, the groove and billet need to do equivalent processing [4, 5].According to the principle of constant width; both are equivalent to the rectangle.

The mean radius of the groove can be obtained by

$$\bar{h} = \sqrt{3}\pi(R^2 - 90^2)/9r_d \quad (9)$$

The equivalent height of billet can be calculated by

$$\bar{H} = r_d(\sqrt{3}\pi/3 - 3/4)/3 \quad (10)$$

The biting angle can be calculated by

$$\cos\bar{\alpha} = \bar{\mathrm{R}}_{\mathrm{d}} - \Delta\bar{h}/\bar{\mathrm{R}}_{\mathrm{d}} \quad (11)$$

Where $\Delta\bar{h} = \bar{h} - \bar{H}$; $\bar{\mathrm{R}}_d = \mathrm{R}_d + \bar{H}$

Respectively substituting Eqn.(9) (10)(11)into Eqn.(5)(8), $\bar{\gamma}$ and $\bar{s}$ can be obtained by

$$\bar{\gamma} = \bar{\alpha}/2(1-\bar{\alpha}/2\rho) \quad (12)$$

$$\bar{s} = \left(1 + \bar{R}_d\left(1-\cos\bar{\gamma}\right)/r\right)^2 \cos\bar{\gamma} - 1 \quad (13)$$

3 **Numerical simulation and analysis of results**

3.1 Establishment of geometrical model

The DEFORM-3D software was used for the numerical simulation. The process geometrical model (Figure 3), worked out for the calculations needs, consists of three rotating tools – profiled rolls (moving in the same direction with the same velocity of the punch), pusher pushing the charge with velocity of 16mm/s,and charge modeled by means of hexahedral elements.

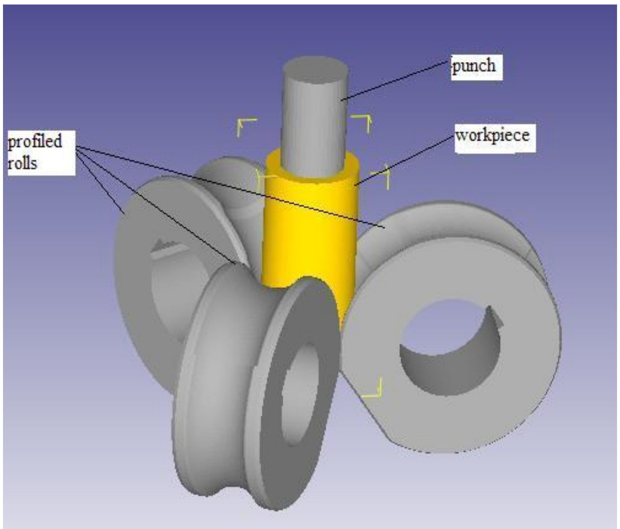


Fig.3 Finite element geometric model

3.2 Simulation conditions

The rigid viscoplastic finite element method was used [8, 9, and 10]. The deformation material used for the simulation is 45Cr, and its size is showed in Fig.4. The tool and die materials are all AISI-H13. In this work, the friction coefficient between the roller and the billet was set at 0.3, using the shear friction driving model [7]. It was assumed that the billet was heated up to 1050 ℃., and the initial temperatures of the roller and die were set at 120 ℃.

Contact heat conductor coefficient: $11W \cdot m^{-2} \cdot K^{-1}$; heat exchange coefficient: $0.02W \cdot m^{-2} \cdot K^{-1}$ [11].The billet is divided to 65844 tetrahedron elements with 14782 nodes. The time increment is set as 0.0 5 s for each FEM iteration step.

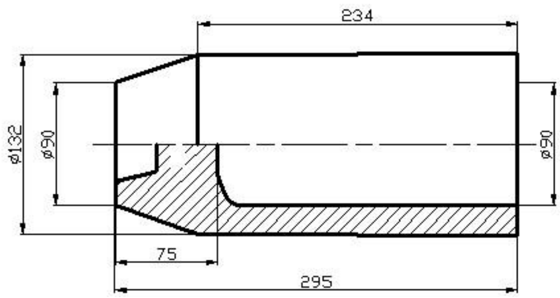
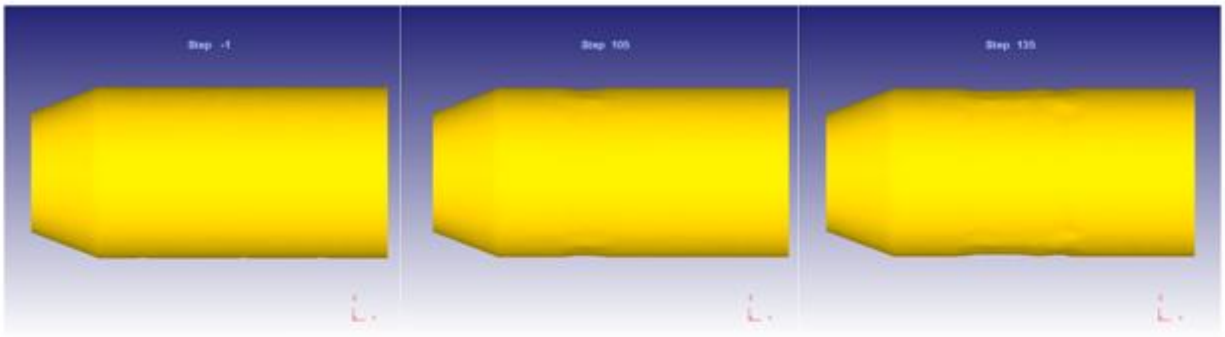


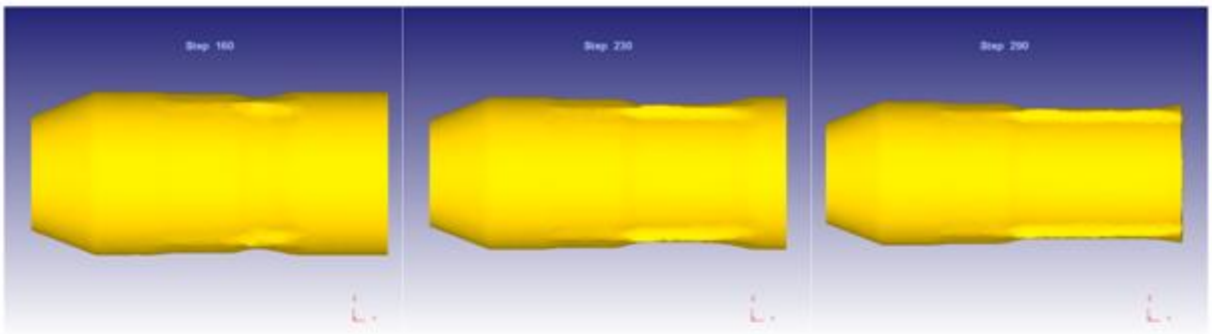
Fig.4 Extrusion blanks

3.3 Simulation results and analysis

The conducted numerical research allowed for analyzing of the progression of part shape during the rolling-extrusion process. According to Fig.5, the process has experienced “nipping” “stable rolling”, “rolling out” three stages. The billet obtains the expected shape.



Step 1 Step135 Step 145



Step 180 Step 230 Step 270

Fig.5 Simulation process of forming

3.4 The forward slip value compare

The theoretical results have been compared with the experimental data. As showed in Table 1, the theoretical results are basically in agreement with the experimental data and approaches that well. So, this theoretical model can be applied to rolling-extrusion process.

Table.1. value of forward slip

Stage of deformation	Radial reduction(mm)	Simulation value (%)	Theoretical calculation value (%)
1	3	5.95	6.15
2	6	6.51	6.89
3	15	7.42	7.95

4 Physical experiment validations

In this work, use press machine of 630 tons, and a simple equipment of rolling-extrusion (Fig.6) to do the physical experiment. Water-based graphite was used as a lubricant. The result showed the size of parts basically meet the requirements, and the material utilization increased by 19%, compared with traditional methods.

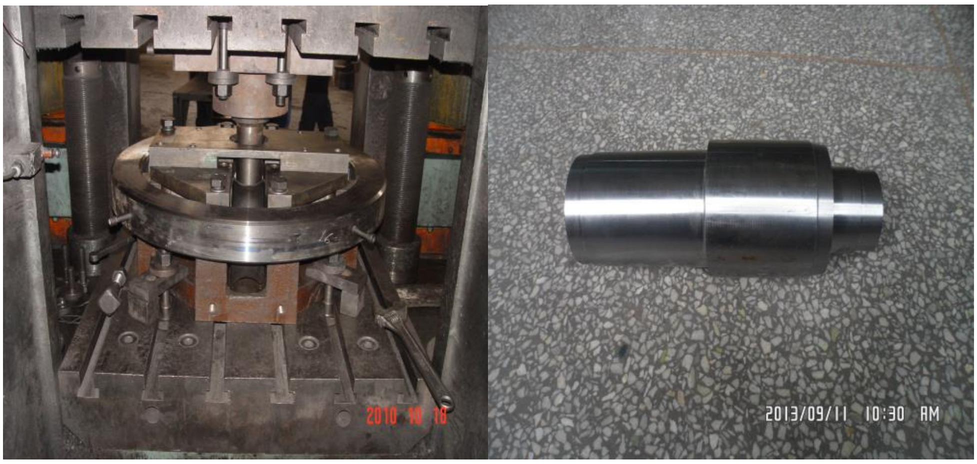


Fig.6 Forming equipment and trial parts

CONCLUSION

（1）The variable wall thickness cylinders parts can be accurately worked out, by using the way of rolling-extrusion, and the material utilization increased by 19% ,compared with traditional methods.
（2）The forward slip model was verified by the numerical simulations and physical experiment .This theoretical model can be applied to rolling-extrusion process.

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