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MECHANISM OF INTEGRATED FORMING OF SHAPE AND INNER HOLE OF HOLLOW AXLE

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The paper introduces a new technology of the integrated forming of shape and inner hole of hollow axle. Firstly, the design of the process is described. Secondly, the range of feed angle of two sets of rolls and the principle to be followed are explained. Finally, the rolling process of hollow axle is simulated by Finite Element Method (FEM), and the variation law of load parameters and the distribution law of temperature and effective plastic strain in the rolling process are analyzed.The numerical results verify the feasibility of rolling hollow axle with this process.

Keywords: three-roll skew rolling, hollow axle, temperature, strain, FEM

INTRODUCTION

Hollow axle is the core component of high speed train. Compared with solid axle, it has the advantages of small axle mass, convenient for ultrasonic testing, and reducing the force between wheel and rail. At present, the main forming methods of hollow axle are open-die forging and precision forging, but these two traditional forming methods have their own limitations, such as low forming rate, low material utilization and large production noise of open-die forging; low material utilization and high investment of precision forging [1].

With the increasingly serious environmental problems, energy saving and environmental protection, high production efficiency and near-net forming of parts play an increasingly important role in the production practice. Many scholars have made a lot of efforts in these directions. Pater et al. produced two kinds of standard train shafts with three high skew rolling mill, and simulated the process with finite element method. The results verified the feasibility of the technology [2]. Wang Fujie et al. proposed TSR (Tandem Skew Rolling) technology,which can complete the piercing and rolling of seamless steel tube on one rolling mill. They verified the process by experiments and FEM, and obtained the variation law of rolling force and rolling torque in the process, and the distribution law of stress, strain and temperature on the workpiece [3]. Romanenko et al. Proposed a method to prepare hollow billets for hollow axles of trains on a two-high piercing mill . In order to prepare high quality ultra thick wall billets, a deformation system and arrangement of deformation zone of two-high piercing mill were proposed [4].

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According to the work done by predecessors, this paper creatively proposes the integrated forming of shape and inner hole of hollow axle, that is, the two processes that piercing and rolling step shaft are completed in one stage.And the process is simulated by finite element method to explore the feasibility.

DESIGN OF INTEGRAL FORMING OF HOLLOW AXLE SHAPE AND INNER HOLE PROCESS

The process schematic diagram of the integrated forming of shape and inner hole of hollow axle is shown in Figure 1. There are two sets of rolls in this process, namely piercing rolls and rolling rolls, which are used to form inner hole and stepped shaft respectively. Firstly, the billet is pushed to the deformation area of the piercing section by the pushing plate and bitten by the rolls. After the billet passes through the deformation area of the piercing section, it becomes a hollow bloom. Then the hollow bloom reaches the deformation area of the rolling section and bitten by the rolling rolls. Through

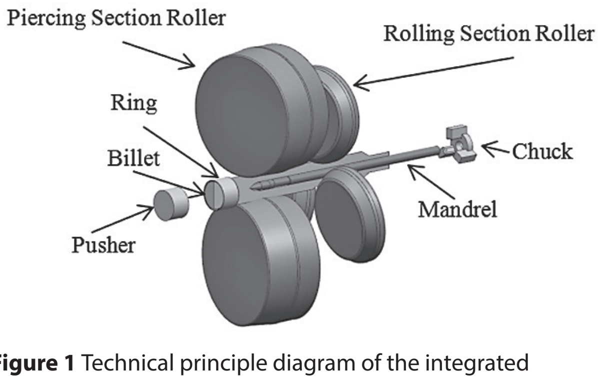

Figure 1 Technical principle diagram of the integrated forming of shape and inner hole of hollow axle

the radial movement of the rolling rolls, the hollow bloom is rolled into a ladder shaft with a certain size. When the whole billet passes through the deformation area of the piercing section,the chuck behind the rolls bite the shaft and move axially coordinating with the radial speed of the rolls until the rolling is completed.

As shown in Figure 2, The piercing rolls and the rolling rolls are formed with the central axis at an angle of α_1 and an angle of α_2 respectively, where α_1 can be taken from 7° to 10° and α_2 can be taken from 8° to 12°. It is easy to know that there must be a continuous rolling relationship between the two sets of rolls in the process of rolling hollow axle, and the metal flow in the deformation area of the two sets of rolls needs to meet the rule of volume flow rate, that is:

$$\Delta_1 = \Delta_2 \quad (1)$$

$$F_1 v_1 = F_2 v_2 \quad (2)$$

Where: Δ is the volume flow rate at any cross section, F_1 is the cross sectional area of workpiece at the outlet of piercing section, F_2 is the cross sectional area of workpiece at the outlet of rolling section, v_1 is the outlet velocity of workpiece of piercing section, v_2 is the outlet velocity of workpiece of rolling section.

FEM SIMULATION OF THE INTEGRATED FORMING OF SHAPE AND INNER HOLE OF HOLLOW AXLE

In order to explore the feasibility of the technology, the axle rolling process is simulated with the simufact v.14 software, as shown in Figure 3. In order to save the computer running time, the size of the hollow axle rolled in this simulation is one fifth of the original size, as shown in Figure 4. To reproduce the Mannesmann effect, the billet used in the simulation is a cylindrical rod with a diameter of 43 mm and a length of 250 mm and a 2 mm diameter hole in the center [5]. The material of cylindrical rod is 30CrMoA, which is a special material for high-speed railway axle. The flow stress constitutive equation of 30CrMoA steel is [6,7]:

$$\dot{\varepsilon} = 3,67 \times 10^{9} [sinh(0,011\sigma_p)]^{4,403} exp(-\frac{261850}{RT}) \quad (3)$$

Where: $\dot{\varepsilon}$ is strain rate/s^{-1}; σ_p is yield stress; R is gas constant (8,314 J·mol^{-1}·K^{-1}); T is temperature /K.

The geometric parameters of the two sets of rolls are shown in Table 1. It is worth noting that in order to meet rule of volume flow rate, the rotation speed of the rolling section rollers is not constant. 55 rpm is the rotation speed when rolling section rollers roll the middle long shaft section of the hollow axle.

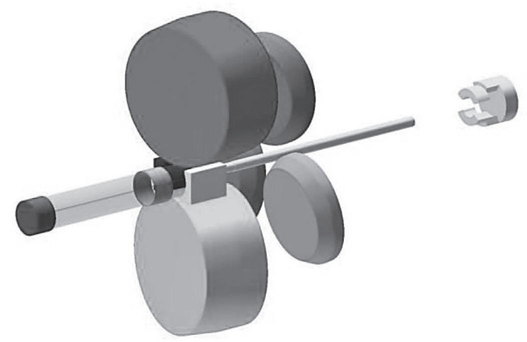

Figure 3 Simufact designed geometrical model of the process

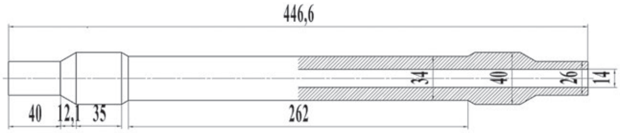

Figure 4 Dimensions of hollow axle

Table 1 **The tools geometric parameters**

Section / Parameter	Piercing Section	Rolling Section
Feed angle /°	8	10
Roller diameter /mm	195	150
Roller length /mm	103,5	35
Roller revolution /rpm	20	55
Roll gap /mm	3,5	15
Plug advance /mm	10	
Mandrel diameter /mm		40

The other parameters are as follows: the friction coefficient between the piercing rolls and billet surface is 0,8, the friction coefficient between the rolling rolls and hollow bloom surface is 0,9, the friction coefficient between other tools and billet surface is 0,05, the contact relationship between the chuck and workpiece is set as bonding; the temperature of each tool is set as 150 °C, the temperature of the billet is set as 1 100 °C; a passive rotation is set at the plug; The thermal conductivity between the tools and the billet is 10 000 W/ (m^{2}K), and the maximum diameter compression ratio of the billet in piercing section is 10 %.

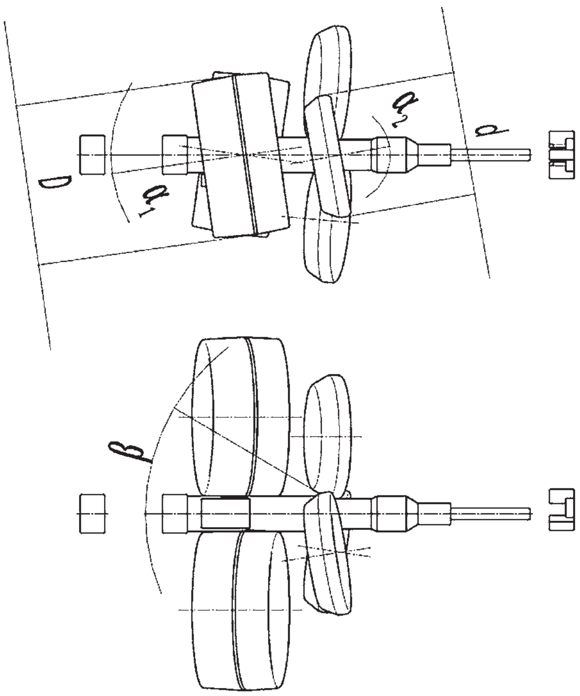

Figure 2 Design of the process for producing hollow axle

FEM RESULTS

The process of finite element simulation is shown in Figure 5. It can be seen from the figure that the billet is rolled into a hollow bloom in the piercing section first, and then the hollow bloom is rolled into a stepped shaft with a certain size in the rolling section. This process skips the reheating stage of the hollow bloom and saves energy and time,which is very beneficial for rolling metal with a narrow temperature range. From the final shape, except for the allowance on the end of the axle and the spiral lines on the long axle section , the shape is close to the standard axle, so it is feasible to form hollow axle by this process.

The radial load of the piercing rolls and the rolling rolls, the axial load of the plug are shown in Figure 6. It can be seen from the figure that when there is a continuous rolling relationship, the radial load of the rolling rolls is smaller than that of the piercing rolls, and its value varies with the change of cross sectional reduction. Their peak value appears in the place with large cross sectional reduction. It is worth noting that the minimum axial load of the plug appears in the place with the largest cross sectional reduction.Because when the hollow bloom contacts the rolling rolls, its axial speed suddenly decreases, which leads to the reduction of the axial force on the plug; Similarly, the maximum axial load of the head appears when the speed of the workpiece increases suddenly, which is attributed to the sudden raising of the revolution of rolling rolls.

Figure 5 The rolling process of hollow axle

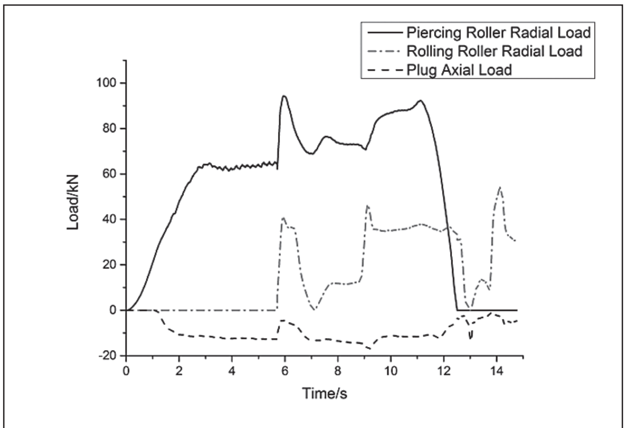

Figure 6 Loads acting on the rolls(radial load) and plug (axial load) in the integrated forming of shape and inner hole of hollow axle

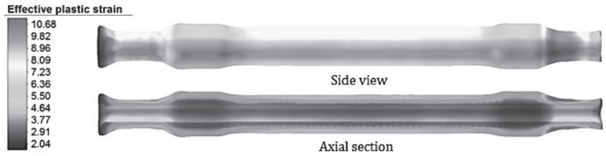

Figure 7 Distribution of effective strain in hollow axle

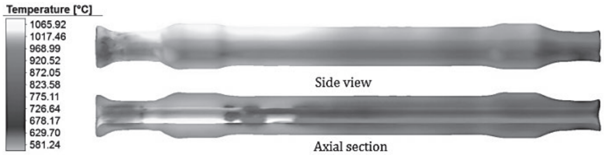

Figure 8 Distribution of temperature in hollow axle

The effective plastic strain distribution of hollow axle is shown in Figure 7. It can be seen from the figure that the strain mainly occurs on the outer surface of the axle, and the maximum value appears at the place with the largest cross sectional reduction, and the minimum value appears at the inner surface of the axle. At the same time, according to the direction of friction force, The flow direction of the material in the process is mainly a circumferential flow. And compared with the forging process, the hollow axle formed by this process makes full use of materials and avoids the waste of materials.

The temperature distribution of hollow axle is shown in Figure 8. It is obvious from the figure that the temperature of the workpiece in the contact area with the plug is low, which is due to the heat transfer between the workpiece and tools. At the same time, it can also be seen that the surface temperature of workpiece contacting with the roller is higher than that contacting with the plug, which is due to the large plastic deformation on the surface of the workpiece contacting with the roller. The heat generated by the plastic deformation makes up for the lost heat, and that is why the temperature of the workpiece is always kept within the rolling temperature range.

CONCLUSIONS

The following conclusions can be drawn from the simulation

- It is feasible to product hollow axle with integral forming of hollow axle shape and inner hole process;
- The cross sectional reduction and axial velocity are the decisive factors of radial load and axial load respectively;
- During the forming process, the temperature of the workpiece is always within the range of the rolling temperature, which improves the rolling efficiency and saves energy;
- Because the piercing process and rolling process are completed on one machine, integral forming of hollow axle shape and inner hole process saves space of factory;

- Because of the existence of the allowance and surface spiral lines, the process needs further improvement.

Acknowledgments

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Note: The responsible translator for English language is C. Q. Ye, Ningbo, China