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FEASIBILITY ANALYSIS OF SHORT PROCESS FLEXIBLE PRECISION FORMING OF ALUMINUM ALLOY AUTOMOBILE HOLLOW SHAFT

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Aiming at the large weight of automobile steel solid shaft, this paper innovates aluminum alloy hollow shaft. The rolling process of automobile hollow shaft was simulated by using the short process flexible precision forming process and the Finite Element Method (FEM). The variation of the shape and inner hole of the rolled piece, the roundness of the outer surface and the wall thickness during the rolling process were analyzed. The numerical results verify the feasibility of rolling aluminum alloy automobile hollow shaft by this process, and provide a theoretical basis for forming aluminum alloy automobile hollow shaft in China.

Key words: aluminum alloy, automobile, hollow shaft, rolling process, FEM

INTRODUCTION

The axle is an important part of the whole vehicle. Compared with the solid axle, the hollow axle is lighter and has greater specific strength and stiffness. Aluminum alloy has the advantages of corrosion resistance and easy processing. Therefore, the development of aluminum alloy hollow shaft instead of the existing steel solid shaft can realize the lightweight of automobile.For aluminum alloy automobile hollow shaft manufacturing, domestic research results are less. Zhao Jing et al. [1] selected 6 series aluminum alloy to analyze the multi-wedge forming mechanism of cross wedge rolling for shaft parts of a agricultural vehicle half shaft. Shi Jian [2] studied the low pressure casting forming process of automobile aluminum alloy hollow control arm. In terms of forming technology, Pater et al. [3] innovated a new three-roll skew rolling process with variable roll spacing, and verified that this new process can be used for step forming. Zhang et al [4] verified that the three-roll cross rolling process can reduce the diameter of the hollow shaft with equal inner diameter ; Ye et al. [5] established a numerical model of hollow high-speed railway axle made by three-roll cross rolling and piercing integrated process, and verified the feasibility of this process.

This paper innovates aluminum alloy hollow shaft instead of steel solid shaft. Aiming at the difficulty of inner hole processing, the hollow shaft short process flexible precision forming process is used. The feasibility of rolling aluminum alloy automobile hollow shaft was discussed by finite element method.

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AXLE SHORT PROCESS FLEXIBLE PRECISION FORMING PROCESS PRINCIPLE

The short process flexible precision forming process (Figure 1) refers to pushing the blank into two sets of rolls for continuous deformation and rolling out the desired shape. These two sets of rolls are piercing roll and reducing roll, respectively, in order to form the inner hole and shape of the shaft. The whole rolling process includes billet biting, piercing and reducing stages. Firstly, the billet is pushed from the push plate to the deformation zone of the perforation section and bitten by the roll. In the perforation stage, two rolls with feed angle α are symmetrically distributed in space. The rolling piece advances axially by the friction force between the rolling piece and the roll, and perforation occurs when it meets the ejector rod. The principle of the reduction stage is that the three conical rolls with a feed angle of β are distributed in a positive triangle in space. They can not only provide axial power for the rolled piece, but also do radial feed motion.

In this process, the solid billet is perforated into hollow by piercing roller, and the inner hole forming can be realized without machining. At the same time, through the multi-degree-of-freedom active control tooling of the reducing roller, the precise forming of the

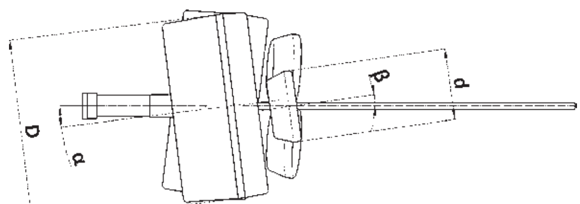


Figure 1 Short process flexible precision forming process of hollow shaft

step shaft can be flexibly realized, so as to realize the flexible and precise forming of the hollow shaft short process.

FINITE ELEMENT SIMULATION OF SHORT PROCESS FLEXIBLE PRECISION FORMING OF AXLE

In order to verify the feasibility, the rolling process of automobile shaft is simulated by simufact 16 software, and the geometric model is shown in Figure 2. According to the principle of rolling equal volume, a cylindrical billet with a diameter of 43 mm and a length of 255 mm was used in the simulation, and a hole with a diameter of 2 mm was set in the center. According to the principle of rolling symmetry, only one car half shaft is rolled, and the size is set to half of the original size, as shown in Figure 3.

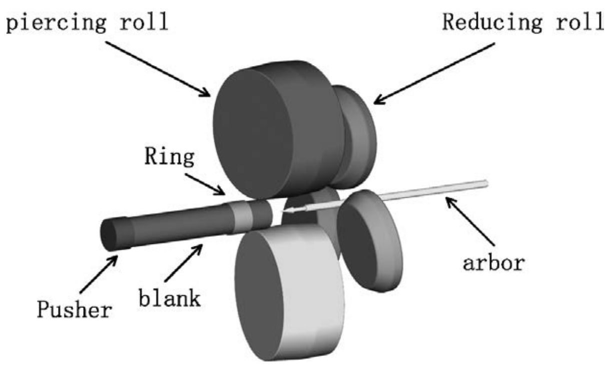


Figure 2 Geometric model of short process flexible precision forming of hollow shaft

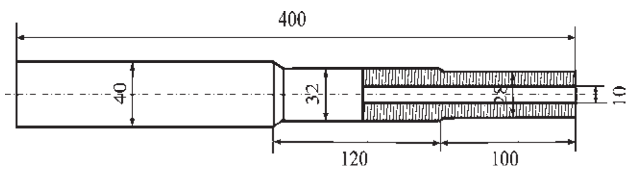


Figure 3 Axle dimensions

This process adopts hot rolling method and selects A6061 aluminum alloy, which is an aluminum-magnesium-silicon alloy and is widely used in automotive parts. Because different process parameters will also affect the temperature of the workpiece during the rolling process, the rolling temperature is set to 450 °C.

The geometric parameters are shown in Table 1. It's worth noting that in the process of many simulations, it's found that to ensure the smooth rolling of the continuous rolling, it's necessary to meet the speed ratio of the two groups of rolls, but the axial speed of the rolled piece when rolled by two groups of rolls at the same time is less than that when rolled by only one group of piercing rolls. Therefore, in order to avoid the phenomenon of stacking at the reducing roll, it is necessary to appropriately increase the speed of the reducing roll.

Other parameters: the friction coefficient between the piercing roller and the rolled piece is 0,5, the friction

Table 1 **Die geometry parameters**

Section \ Parameter	Piercing Section	Rolling Section
Feed angle /°	8	10
Roller diameter /mm	195	150
Roller length /mm	95	35
Roller revolution /rpm	20	60
Plug advance /mm	15	
Mandrel diameter /mm	10	10

coefficient between the reducing roller and the hollow rolled piece is 0,4, and the friction coefficient between other tools and the blank surface is 0,3 ; the mold temperature was set to 150 °C, and the ambient temperature was 20 °C. The jacking rod is set to passive rotation ; the thermal conductivity between the tool and the blank is 10 000 W / (m^2K) .

FEM RESULTS

The finite element simulation of the hollow shaft forming process is shown in Figure 4, which has gone through the stages of perforation, first reduction, second reduction and piercing. After the cylindrical billet enters the piercing stage, the piercing roller group cooperates with the ejector rod to form the inner hole instead of the traditional drilling process. At this time, the rolled piece is elongated axially. After that, the dynamic roll rolling was carried out in the reduction stage, and the two reduction reduction reductions were 6mm and 4mm respectively, and the hollow billet was rolled into stepped shafts with different outer diameters. The process used in this study saves energy and improves efficiency compared with traditional piercing and rolling.

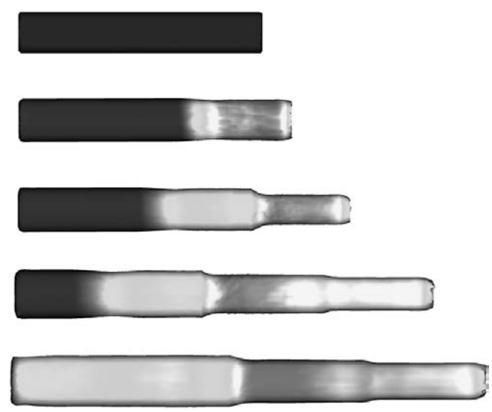


Figure 4 Hollow axle forming process

As shown in Figure 5, by comparing the forming result shaft with the target shaft, it can be seen that the length and diameter reduction of each stage in the rolling process are basically consistent with the design. From the cross section of the rolled piece, it can be seen that the inner hole of the shaft is formed evenly, and there are no processing defects such as slip, workpiece collapse and deformation. In addition to a small amount

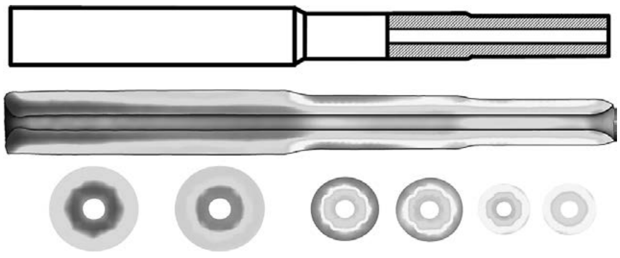


Figure 5 Comparison of forming shaft and target shaft

of material head at the shaft end, the shape and inner hole forming of the rolled piece meet the design requirements, so it is feasible to use this process to form the aluminum alloy automobile hollow shaft.

In the process of forming aluminum alloy automobile hollow shaft, the roundness of the rolled piece is also an important index of the forming quality. It indicates the degree of the outer contour of the cross section of the rolled piece is close to the circle. The formula for calculating the roundness of the outer surface of the rolled piece is :

$$R = 1/2\ (Dmax - D\ min) \quad (1)$$

In the formula, Dmax is the maximum diameter of a section profile of the rolled piece, and Dmin is the minimum diameter. The smaller the roundness value is, the closer the cross-section contour is to the theoretical circle, and the better the forming quality is.

Taking the aluminum alloy automobile hollow shaft blank after rolling as the research object, as shown in Figure 6, a total of 9 cross sections of the perforated section, the first reducing section and the second reducing section of the hollow shaft blank are intercepted equidistantly for research. Taking the perforation section as an example, after intercepting three cross sections, 20 points are evenly taken on the outer contour of each sampling section, and the section diameter is obtained by the coordinates of each point. Then, the roundness of the outer surface contour of each section is calculated according to the formula. The roundness of the perforated section of the blank can be estimated by taking the average value of the roundness of the three sections.

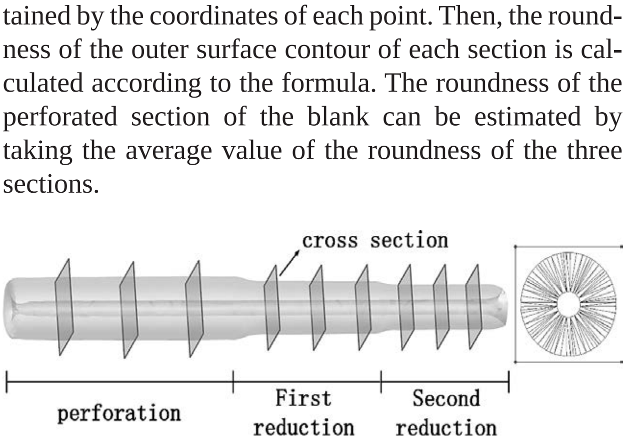
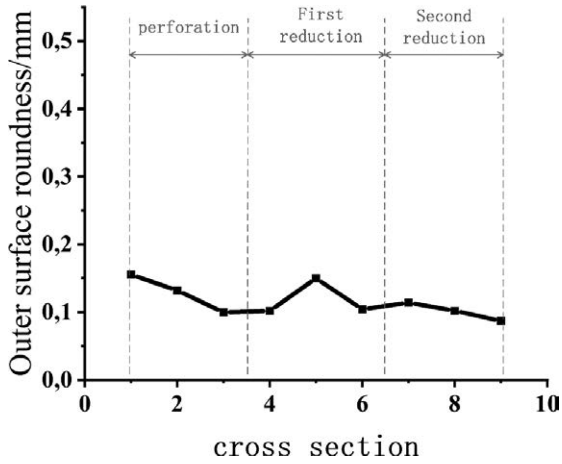
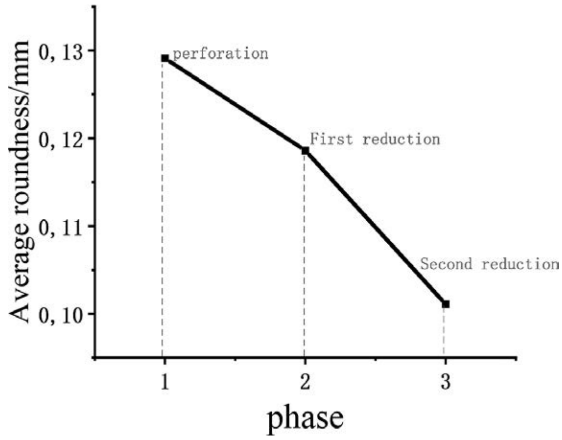


Figure 6 Equal distance intercept hollow shaft

The roundness of each stage is calculated as shown in Figure 7(a). Taking the average value, the roundness of the three sections is : 0,1291 ; 0,1186 ; 0,1011. As shown in Figure 7(b), it can be seen that the roundness of the outer surface of the rolled piece at each stage after forming is small, and the overall forming quality is good. The average roundness of the perforation stage is



(a)



(b)

Figure 7 Outer surface roundness of axle

the largest, and the average roundness of the second reducing stage is the smallest.

During forming, if the rotational speeds of the two sets of rolls do not match, the wall thickness of the rolled piece will be uneven, resulting in large machining allowance and low material utilization. Therefore, the wall thickness uniformity of the axle must be ensured during the rolling process.

Now, the axle after rolling is taken as the research object, and the nodes are evenly selected in the measurement area and the wall thickness changes are analyzed. As shown in Figure 8, the surface lines along the longitudinal section of the rolled piece are selected at 20 nodes in the perforation section, the first reduction section and the second reduction section, and the wall thickness variation of each section is studied respectively. At the same time, the wall thickness variance S is introduced to represent the wall thickness uniformity, that is, the difference between the wall thickness of each node and the average wall thickness is calculated.

$$S^2 = \frac{1}{m}\sum_{n=1}^{m}(t_n - \bar{t})^2 \quad (2)$$

Where, m is the number of nodes (m = 20), t_n is the wall thickness of nodes, and t is the average wall thickness of each node.

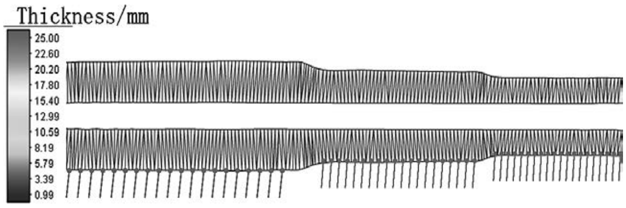


Figure 8 Select nodes

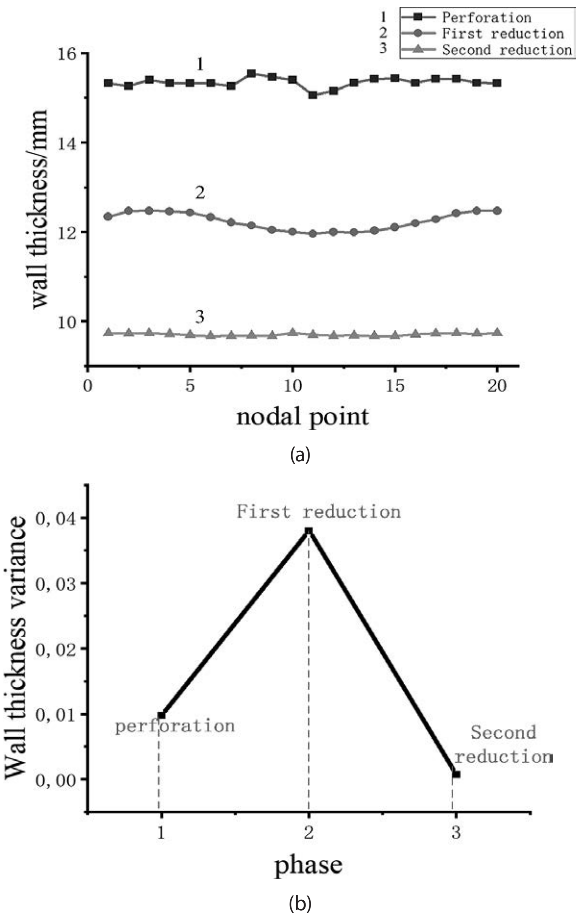


Figure 9 Variation law and variance of hollow automobile axle wall thickness

The wall thickness of the three stages of the axle is shown in Figure 9. The variance of each stage is: 0,01235;0,037989;0,00073. The wall thickness fluctuation of the second reducing section is the smallest, which is because the axial velocity of the rolled piece is the smallest and the wall thickness uniformity is good. It can be seen from the wall thickness variance diagram that the wall thickness variance of the first reducing section is the largest. This is due to the addition of a set of rolls during the process from perforation to reducing. As the rolling force increases, the rolled piece will vibrate slightly, resulting in uneven wall thickness.

CONCLUSIONS

Based on the above research, the following conclusions can be drawn :

- It is feasible to produce aluminum alloy automobile hollow shaft by this process;
- There is no slip, collapse, deformation and other defects in the forming process. Except for a small amount of material head at the shaft end, the forming of the rolled piece meets the design requirements;
- The roundness of the outer surface of the rolled piece is small at each stage after forming, and the overall forming quality is better;
- The wall thickness variance of the first reduction section is the largest, which is due to the slight vibration of the rolled piece with the increase of rolling force;

Acknowledgments

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REFERENCES

[1] Zhao J., Xu Q.B., Jiang X.M., et al. Mechanism Analysis of Aluminum Alloy Shaft Forming with Multi-wedge Cross Wedge Rolling [J]. Hot Working Technology 45(2016)3, 121-124.

[2] Shi J., Su W.Q., Sun N.Y. Development of Low Pressure Casting Technology for Hollow Control Arm of Automobile Aluminum Alloy [J]. Foundry Engineering 46(2022)1, 71-75.

[3] Pater Z., Tomczak J., Bulzak T. Numerical analysis of the skew rolling process for main shafts [J]. Metalurgija 54(2015)4, 627-630.

[4] Zhang S., Shu X.D., Xu C., et al. Simulation and experiment of reduction of equal-diameter hollow shafts with three-roll skew rolling [J]. Procedia Manufacturing 50 (2020)1, 183-186.

[5] Ye C.Q., Shu X.D., Xia Y.X., et al. Mechanism of integrated forming of shape and inner hole of hollow axle [J]. Metalurgija 61(2022)1, 167-170.

Note: The responsible translator for English language is Y.M.Li, Ningbo, China