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STUDY ON THE CONTROL OF END QUALITY BY ONE CLOSED CROSS WEDGE ROLLING BASED WEDGE BLOCK

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The paper presents a new method of one closed cross wedge rolling (CWR) based wedge block to achieve near net forming of CWR shafts. The modeling is performed by using the Finite Element Method (FEM) software DEFORM-3D. The metal flow rule of the shaft is clarified by analyzing the strain and displacement field of the shaft. The results demonstrate that the concave heart value of rolled part end will be reduced by about 70 % by one closed CWR based wedge block, comparing it with the case without wedge block. And also the rolling experiments are performed the result of which provides reliable theoretical basis for achieving near net forming of CWR.

Key words: cross wedge rolling, concave heart, wedge block, strain, FEM

INTRODUCTION

Cross wedge rolling (CWR) is used to form axisymmetric parts and shafts that offer a great number of advantages, such as high production yield, effective material utilization, and eco-friendliness of the process [1]. Despite these advantages, there are also some defects of concave heart in the course of rolling shafts. The material utilization of rolled part hardly surpasses 85 % using CWR technique [2]. Generally speaking, in traditional open rolling, the concave heart of shafts end is generated because that the flow rate of surface metal of the rolled part is faster than that of core metal during the rolling process. However, the concave heart is generated in closed rolling due to the action of the forming wedge in initial stage of rolling. Hence, according to the characteristics of two rolling technique, the paper presents a new technique of one closed CWR based wedge block to solve the defects of concave heart.

In recent years, Pater et al. [3] presented a thermomechanical model of cross wedge rolling for producing a stepped shaft and performed corresponding numerical analysis. The results demonstrated that new CWR-based manufacturing processes can be designed in a simpler manner. Zu et al. [4] adopted the method that the wedge block was set on both sides of the mould to restrain the generation of the concave heart, when multi-wedge rolling mould was designed, and finally gained remarkable benefits. Shu et al. [5] created a new technique for forming small stub bar of shafts, also known as pressure-feed CWR, which provided billet for open rolling, because it utilized the characteristic of metal flow during open rolling process.

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On the basis of the above studies, in the paper, the numerical simulation and rolling experiment are performed by one closed CWR based on wedge block. And the analytical results are validated through comparing them with experimental data. The concave heart can be relatively remarkable reduced by one closed CWR based on wedge block. The result may play a key role in promoting the development of CWR techniques.

THE MODELING OF FINITE ELEMENT METHOD

Figure 1 shows the numerically simulated CWR process for forming an oil pump shaft. In simulation, the intermediate step of the shaft is formed at the shrinkage φ section (i.e the measurement of deformation in CWR, where φ = 1-; d_0 is the diameter of the billet, d is the diameter of the shaft being rolled) when it is set equal to 57,7 %.

Figure 2 shows the mould used in the CWR process for forming an oil pump shaft. Known from Figure 2, the closed rolling is prior to the open rolling, and the intermediate step is formed at the open rolling stage. In the middle of mould, t a groove is set with 30 mm's width and the 0,5 mm's of depth, in order to avoid the axial movement and meanwhile to increase the friction force. The Process parameters on the mould and the rolled part are showed in Table 1.

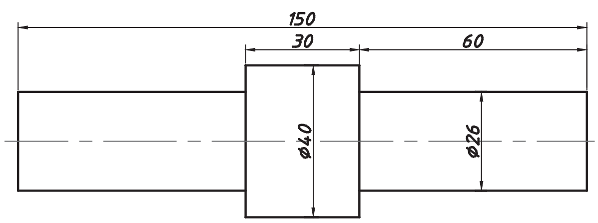


Figure 1 The oil pump shaft

Table 1 **The process parameters**

Forming angle of closed rolling α_1 / °	Angle of wedge block α_2 / °	Forming angle of open rolling α_3 / °	Stretching angle of closed and open β_1, β_2 / °
30	50	20	9
The diameter of billet d_0 / mm	The length of billet L_0 / mm	The reserved depth h / mm	the section shrinkage φ / %
40	60	0,5	57,7

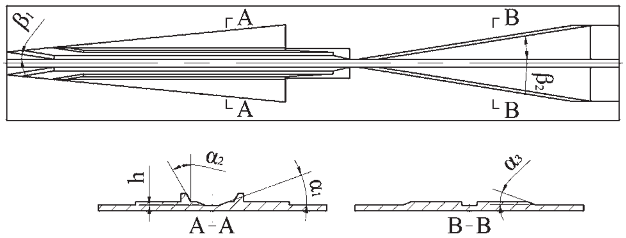


Figure 2 The expanded view of the mould and cutaway view of two cross section

Firgure 3 shows the designed FEM model of the one closed CWR based wedge block. From Figure 3, the roller is regarded as rigid body, while the rolled part is regarded as an elastic-plastic body. The guides are respectively set on both sides in radial direction of rolled part to avoid the radial movement of rolled part. The billet uses 42CrMo material which shows high integrating mechanics performance. What's more, the billet with a diameter of 40 mm and a length of 60 mm is heated to 1 200 ℃ to keep 1 050 ℃ in the initial rolling, and then divided by tetrahedral mesh by 32 000. The friction factor between the rolled part and mould is set equal to 2.

FEM ANALYSIS RESULTS

Strain field analysis

Figure 4 shows the axial strain in different intermediate longitudinal section of rolled part in the course of rolling. From Figure 4a, the surface metal of rolled part's end is squeezed to produce radial and axial deformation in the initial stage of closed rolling. The nonformation metal inside the rolled part hinders the flow of surface. When the surface metal flow to the core, it leads the surface metal to flow to both ends. Therefore, the deformation of metal and tensile strain is becoming

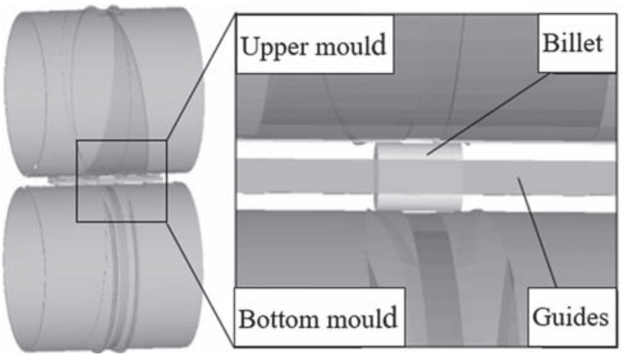


Figure 3 The FEM mould

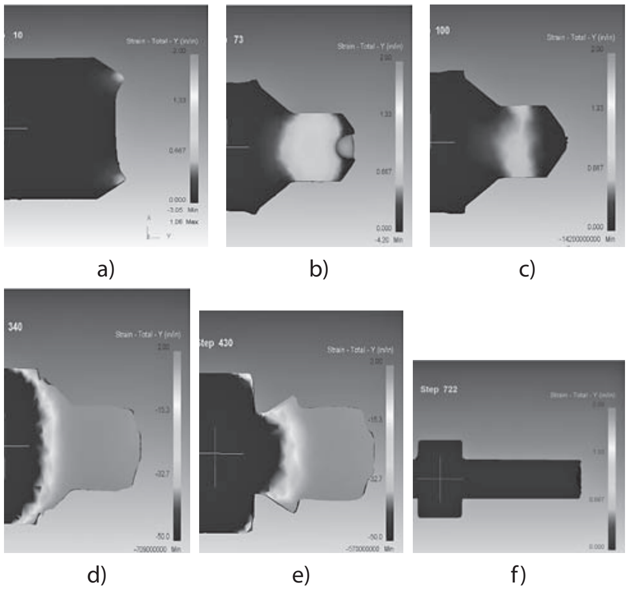


Figure 4 The axial strain in different intermediate longitudinal section of rolled part

more and more small from the outside to the inside, lead the interaction force among metal to be more and more small. With the gradually increasing strain difference of the core and the outside metal, the concave heart starts to form.

Form Figure 4 b, in the stretching stage of closed rolling, the concave heart gradually increases. Due to the action of wedge block, the outside metal starts to flow to the concave heart, leading the concave heart to decrease. There are still spaces in metal of end at the finishing stage of closed rolling. In addition, the rolled part's end is under the uniform extrusion strain, and the section being rolled produces tensile strain. The rolled part's end gradually moves farther aaway from the forming wedge because the section being rolled is still extended in stretching stage.

Form Figure 4 c, in the finishing stage of closed rolling, the concave heart no longer increases, and the cylindrical degree of the section being rolled is increased by the action of mould. The surface metal which has taken shape is forced to flow to both ends of rolled part, so the length of rolled part further increases and the concave heart gradually disappears. And finally, the conical ends of rolled part are obtained.

From Figure 4 d, 4 e, and 4 f, the oblique step starts to be rolled into the straight step, superfluous surface metal flow to both ends of rolled part, and then the small concave heart will be generated. It can be observed from the strain figure because that the rolled part has obvious homogeneous tensile strain which gradually increases by the central section to the ends. Finally, the rolled part is completed.

Displacement field analysis

In the rolled part's end, the edge point node P1, the half radius point node P2 and the center point node P3

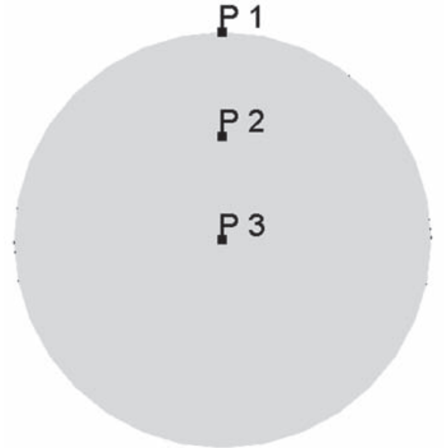


Figure 5 Three tracking points

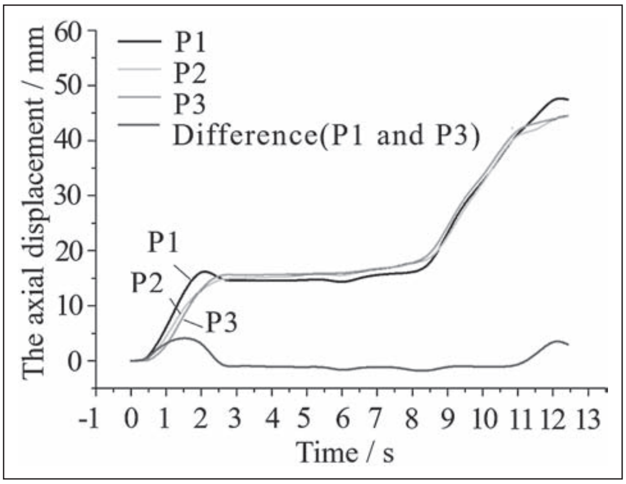


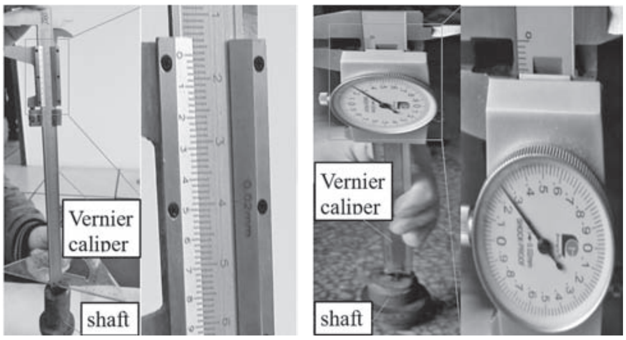
Figure 6 The displacement change curve of point P1, P2 and P3.

are set as the tracking point, as shown in Figure 5. Figure 6 is the displacement change curve of point node P1, P2 and P3 in the overall course of one closed CWR based wedge block. The change curves of three points increase rapidly in the initial stage of closed rolling, but the displacement velocity of points P2 and P3 are slower than P1. The wedge block has not yet worked, because there is maximal strain in the surface under the direct effect of forming wedge in this stage. Enter into the stretching stage of closed rolling, the displacement velocity of three curves decrease rapidly to 0, and the curve of point P1 suddenly decreases in about 2 seconds. The displacements of three points show a slight growth under the action of wedge block, and the effect of wedge block on point node P2, P3 is later than that on point node P1 because the wedge block starts to effect on the surface metal. In this way, some space is provided for point P2, P3 to produce slight axial movement until ends complete contact with the wedge block.

In the finishing stage of closed rolling, the displacement velocity of three curves basically becomes 0. It indicates that the shape of the rolled part's ends no longer has a big change, and the pre-roll forming is basically completed. Entering into the open rolling in 8,5 seconds, the axial displacements of three points sharply rise, but the displacement rate is almostthe same , and the displacement difference keep some. Since the force of mould on the rolled part's ends is smaller, it leads to smaller strain difference of the surface metal around ends is. The rolled part's ends bring total axial displacement until the shape of ends no longer changes.

ROLLING EXPERIMENT

The experimental parameters are consistent with the simulation parameters. The rolling experiments of one closed CWR based wedge block (Figure 7 a) and those without wedge block (Figure 7 b) are performed respectively. Finally, the concave heart measurements are shown in Figure 7. The concave heart analysis of two cases is shown in Table 2. Under the two cases, the errors between the simulational and experimental value are controlled within 10 %. They verified that the simulation results are correct, and that good end quality can be obtained by one closed CWR based wedge block.



a b

Figure 7 The rolling value of concave heart under two cases

Table 2 **The concave heart analysis**

	Simulation value / mm	Experimental value / mm	Error / %
Without wedge block	15,49	14,40	7,04
Based wedge block	5,68	5,26	7,39

CONCLUSIONS

By analyzing the strain and displacement filed of rolled part, concave heart's rule of change is obtained: the concave heart is produced in the initial stage of closed rolling, due to the action of forming wedge; It rapidly increases in the stretching stage of closed rolling, but under the action of wedge block, the surface metal flow to the concave heart until the rolled part's ends become conic shape at the end of closed rolling; Then the oblique step is rolled down to the straight step in the open rolling, and more surface metal flow to the rolled part end, leading the conic shape of end to gradually become flat; Finally, the tiny concave heart will produce at the ends.

The results of simulation and experiment are identical, both of them indicate that the one closed CWR based wedge block can effectively improve end quality of rolled part, and even can make the concave heart be reduced by about 70 % comparing it with the single-open rolling.

Acknowledgements

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REFERENCES

[1] X. D. Shu, Valery Ya. Shchukin, B. S. Sun, et al., Theory and forming technology of cross wedge rolling, Ed, Science Press, Beijing2014.

[2] X. H. Wei, X. D. Shu, Influence rule on tangential force of cross wedge rolling asymmetric shaft, Journal of Central South University 32 (2012) 5, 43-47.

[3] Z. Pater, J. Tomczak, T. Bulzak, Numerical analysis of the cross wedge rolling process (CWR) for a stepped shaft, Metalurgija 54 (2015) 1, 177-180.

[4] W. M. Zu, Study on the key technology of multi-wedge cross wedge rolling forming automobile semi-axis, [Dissertation], Beijing: University of Science and Technology Beijing, 2009.

[5] W. W. Gong, Research microstructure evolution of cross wedge rolling asymmetric shaft parts and non-remnants, [Dissertation], Ningbo: Ningbo University, 2012.

Note: The professional translator for the English language is Qian Qian Yan, Zhejiang, China