Feasibility Analysis of Cross Wedge Rolling (CWR) of Hexahedral Billet

Y Chang1,2, X D Shu1,2 and T Z Chen1,2

1. Faculty of Mechanical Engineering & Mechanics, Ningbo University, Ningbo 315211, China
2. Zhejiang Provincial Key Laboratory of Part Rolling Technology, Ningbo 315211, China

Corresponding author email: shuxuedao@nbu.edu.cn

Abstract. In order to expand the product range of cross wedge rolling (CWR) and realize the CWR of hexahedral billet, the hexahedral CWR is studied. In this paper, a three-dimensional finite element model (FEM) of hexahedral CWR is established by using DEFORM software. In this paper, a three-dimensional FEM of hexahedral CWR is established by using DEFORM finite element software. The change and distribution of equivalent stress and strain in the rolling process of hexahedral billets are analyzed. By tracking the strain in the rolling core of hexahedral billet, the change law of strain in each stage of forming process is obtained. The equivalent strain during the manufacturing process, the obtained CWR of hexahedral billet and round billet are basically the same. The feasibility of CWR of hexahedral billet is further verified by experiments. The research results provide theoretical guidance for realizing CWR of hexahedral billet.

1. Introduction

The CWR is a plastic forming process in which the roll with wedge-shaped die is rotated in the same direction to compress the workpiece radially and extend axially [1-3]. It has the advantages of high efficiency and energy saving, and is widely used in the rolling of round billet. With the development of economy, there are more and more kinds of parts that can be rolled, which makes only the variety of billets can meet the rolling requirements. The research scope has developed from the traditional rolling of symmetrical parts to the theoretical research of rolling of asymmetrical parts. From the ordinary die to the special die, the shape of the billet is gradually expanding [4]. Pater Z. and Tomczak J [5] of the University of Lublin in Poland are mainly engaged in the development of new dies and the research of plate CWR technology. Through the design of dies and die parameters, the technical research of forming ball of cross wedge rolling process is realized, and the product range of CWR process is continuously expanded. Taizhu Chen [6] mainly studied the effect of process parameters on volume loss of one-side head of square billet CWR, the influence of forming angle, broadening angle and section shrinkage on the volume of one-sided blank head was analyzed based on orthogonal experiments of three factors and three levels, which can provide references for expanding the types of CWR billets and choosing reasonable process parameters in square billet rolling. Xuedao Shu [7] of Ningbo University used the DEFORM-3D finite element software to establish the FEM of CWR with the axis end blank forming optical axis, analyzed the influence of the axis end length, step angle, step length, section shrinkage and other rolling process parameters on the force and energy parameters, and
carries out the 1:1 rolling experiment. Wenyu Ma [8] of Beijing University of Science and Technology studied the differences between the round billet rolling and the square billet rolling were obtained by comparing the tangential, axial and radial forces during the rolling process. Yafei Zhang [9] used the point tracking function in DEFORM-3D to analyze the stress change in the radial core of the rolled part, and analyze the most likely cracks in the rolled part. Tomasz Bulzak [10] put forward the idea of hot and warm CWR of ball pins – Comparative analysis, the stress and strain during the rolling at different temperatures was analysed. The variable nature of stress during CWR is more advantageous during hot rolling due to the lower amplitude of stress changes. It can be seen that there are few reports on the research of hexahedral rolling. In order to enlarge the product range of CWR, it is necessary to determine the feasibility of CWR process for hexahedral billet.

In this paper, the numerical simulation model of hexahedral billet rolling process is established by simulation software DEFORM-3D. By analyzing the change and distribution of equivalent stress and strain in the process of hexahedral billet rolling, the equivalent strain in the process of hexahedral billet CWR and round billet rolling is compared, the feasibility of hexahedral billet CWR is further verified by experiments. The results provide theoretical guidance for the realization of CWR of hexahedral billet.

2. Establishment of FEM of hexahedral billet CWR

The geometric model is established and assembled in CREO software and imported into DEFORM-3D simulation software. The simulation model is shown in Figure 1. The pre-processing of FEM is completed in DEFORM-3D software. The setting parameters are as follows:

1. The billet is set as plastic body, the rolling temperature is set as 1050 °, and the material is 42CrMo. (2) In order to save the time of simulation calculation, 1 / 2 rolling model is selected and symmetrical constraints are set at the boundary of symmetrical surface.

3. Tetrahedral free mesh is used to divide the mesh, 80000 mesh number is initially set, set volume compensation to avoid material volume loss.

4. The simulation step is 0.008 second per step and the rolling speed is 0.418 rad / s.

5. Friction coefficient setting: it is selected to be represented by shear friction, and the friction coefficient between billet and die is 2 [11].

Table 1. Simulation process parameters of CWR.

| Forming angle α / ° | Spreading angle β / ° | Section shrinkage Ψ / % | Feed speed v/(mm/sec) | Length of billet l/mm |
|---------------------|-----------------------|--------------------------|------------------------|-----------------------|
| 30                  | 7.5                   | 31.2                     | 0.418                  | 15                    |

Figure 1. FEM of hexahedral billet CWR

3. Finite element analysis

3.1 Distribution of stress and strain
Equivalent stress refers to the equivalent conversion of asymmetrical cyclic stress from the angle of equal strength to symmetrical cyclic stress, which reflects the reaction of comprehensive stress on metal in the forming process [12]. It can be seen from the simulation Figure 2 (a) that in the wedging stage of the hexahedral billet CWR, the deformation first occurs at the periphery of the cross section, and then plastic deformation successively occurs from the outside to the inside, and the metal in the middle of the rolled piece gradually accumulates. In the wedging stage, the billet is basically well formed, the stress distribution is uniform, the local tensile stress is small, similar to the rolling process of round billet, the maximum stress still appears in the contact area. The stretching stage is the main stage of the CWR of hexahedral billet. The compressive deformation gradually increases to the peak value and then decreases to the steady state. As shown in Figure 2 (b), the compressive stress in the contact area is large. In the whole stretching stage, the tensile stress is deformed by the roller stretching the workpiece in the axial direction.

It can be seen from the simulation Figure 3 (a) that the strain at the beginning of the wedging stage first occurs in the contact area, which is similar to the stress distribution. There are radial deformation, lateral deformation and axial deformation in the rolled piece. Under the action of horizontal tangential force, the rolled piece is stretched from the core to the two outer sides in the horizontal direction, and the billet is in the wedging state. At the same time, the flow of metal is hindered by the material. With the gradual thickening of the material along the core to the outer side, the blocking effect is more obvious. It can be seen from the equivalent strain Figure 3 (b) of the stretching stage that the tensile strain occurs in the contact area, which is due to the fact that the metal axial flow stretches the billet in large dimensions. The compressive strain of the die appears on the diagonal of the non-contact area, and it shows a symmetrical radiation distribution, which is obviously different from the rolling of round billet. The strain in the contact area with the die is obviously larger, the strain around the die is concentric distribution, and the strain at the core is the smallest.

3.2 Strain tracking of hexahedral billet core

In the process of CWR of hexahedral billet, in order to show the characteristics of strain change in the core and realize more characterization of limited data, three points P1, P2 and P3 are selected to be
evenly distributed in the axial direction for tracking, and the changes of stress and strain in the core area of axis segment, the core area of intermediate axis segment and the core area of end axis segment in the process of forming are analyzed. The location is shown in Figure 4.

![Figure 4. Distribution of tracking point position distribution](image)

It can be seen from Figure 5 that transverse compressive strain, longitudinal compressive strain and axial tensile strain are generated in the intermediate shaft section of the wedging stage, and the strain increases with the rolling in all directions, with the fastest growth rate during the whole forming period. The anisotropic strain of the metal in the axial section of the symmetry plane and the metal in the axial section of the end is smaller. During the stretching stage, the axial strain mainly occurs in longitudinal compression strain, transverse compression strain and axial tensile strain, and the axial strain grows fastest in this stage. When the tracking point and the wedge point are in the same plane, the transverse strain and the longitudinal strain show the compressive strain, and the strain reaches the maximum; when the tracking point plane and the wedge point plane are 90°, the transverse strain and the longitudinal strain show the tensile strain, and the strain reaches the maximum. The transverse strain and longitudinal strain of the metal in the intermediate shaft also change periodically, but the axial strain hardly changes.

![Figure 5. Strain change at the tracking point of the rolled core](image)

4. Simulation comparison of hexahedral billet CWR and round billet CWR
The hexahedral billet has a cross section dimension of D = 15 mm and a length of L = 30 mm. The round billet of the same volume and cross section dimension is used for rolling, the diameter of the
round billet is about 13.641 mm. Figure 6 shows the simulation results of hexahedral billet and round billet rolling under the same parameters. The equivalent strain comparison of hexahedral billet rolling and round billet rolling is shown in Figure 7.

![Hexahedral billet and Round billet comparison](image)

**Figure 6. Comparison of rolling of hexahedral billet and round billet under the same parameters**

![Comparison of equivalent strain](image)

**Figure 7. Comparison of equivalent strain between hexahedral billet and round billet**

It can be seen from Figure 7 that the equivalent strain trend of hexahedral billet CWR and round billet rolling is basically the same, both of which show a linear growth, and the equivalent strain of metal in axis section of symmetrical plane is the largest. In the process of rolling round billet, the effect of metal in the end of the wedging stage is greater than that in the middle section. After entering the stable stretching stage, the equivalent strain of the intermediate shaft section is the smallest. This is because the metal accumulation around the hexahedral billet is slightly more than that of the round billet in the process of CWR, which results in the maximum value of equivalent strain variation (about 15) of the hexahedral billet is greater than that of the round billet.

5. **Experimental comparison of hexahedral billet CWR and round billet CWR**

The rolling temperature of H630 CWR mill used in the experiment is 1050 °C, and the material and process are consistent with the simulation. As can be seen from Figure 8, the experimental results are basically consistent with the simulation results. The error may be caused by the following reasons: due to the idealized cooling conditions of the rolling piece and the slow drop of metal temperature during the finite element simulation process, the metal flow is better, resulting in the error between the experimental length and the simulation length of the end section. This experiment further verifies the feasibility of CWR of hexahedral billets.

![Comparison of experiment and simulation](image)

**Figure 8. Comparison of experiment and simulation**
6. Conclusion

1) Distribution of stress and strain in CWR of hexahedral billet: in the wedging stage, the deformation first occurs at the periphery of cross section, then plastic deformation successively occurs from the outside to the inside, and the metal in the middle of rolled piece gradually accumulates. The stretching stage is the main stage for the completion of CWR of hexahedral billet. The compression deformation gradually increases to the peak value, and then decreases to the steady state.

2) The trend of equivalent strain of hexahedral billet in CWR is basically the same as that of round billet, both of which show a linear growth, and the maximum of equivalent strain of metal in axis section of symmetrical plane becomes the largest, but the maximum of equivalent strain of hexahedral billet is larger than that of round billet.

3) The results of experiment and simulation show that the rolled piece has good roundness and geometry, which is similar to the rolling of round billet. It further shows that the CWR process of hexahedral billet is feasible.

Acknowledgements

This paper is supported by the National Natural Science Foundation of China (Grant no, 51975301), and the National Natural Science Foundation of Zhejiang Province of China (Grant no, LZ17E050001)

References

[1] Xuedao Shu. Near-net forming of parts rolling: an advanced forming technology with both theoretical and practical value. 2018, *Journal of Ningbo University (Science and Technology Edition)*, **31**(1) pp 55-56.

[2] Zhenghuan Hu, Cuiping Yang, Baoyu Wang. Development of rolling technology of shaft parts in China. 2012, *Journal of Mechanical Engineering*, **48** pp 7-12.

[3] Jing Zhao, Xuedao Shu, Zhenghuan Hu. Research status and prospects of automotive half-shaft forming technology. 2004, *Metallurgical Equipment*, **148** (6) pp 32-34.

[4] Dongping Li, Guangquan Li, Zhibin Bai. Application and new development of cross wedge rolling technology. 2000, *Journal of Harbin Institute of Technology*, **05** pp 97-99.

[5] Pater Z, Bulzak T, Tomczak J. Cross-wedge rolling of driving shaft from titanium alloy Ti6Al4V. 2016, *Key Engineering Materials. Trans Tech Publications*, **687** pp 125-132.

[6] Taizhu Chen, Xuedao Shu. Effect of process parameters on volume loss of one-side head of square billet CWR. 2019, *Metalurgija*, **58** pp 30-34.

[7] Xuedao Shu. Effect of technological parameters on mechanical energy parameters of cross-wedge rolling GH4169 alloy shafts. 2018, *Journal of Plastic Engineering*, **25** (1) pp 52-59.

[8] Wenyu Ma. Analysis of Square Billet Cross Wedge Rolling Process Using Finite Element Method. 2013, *Applied Mechanics and Materials*, pp 271-272.

[9] Yafei Zhang. Analysis of Stress and Strain of the Jujube Arc Parts During Plate Cross Wedge Rolling. 2017, *Journal of Shenyang Ligong University*, **36** (3) pp 21-26.

[10] Tomasz Bulzak. Hot and warm cross-wedge rolling of ball pins – Comparative analysis. 2020, *Journal of Manufacturing Processes*, **90** pp 90-101.

[11] Q. H. Zhang. Finite element numerical simulation of rolling of shaft parts. 2010, *Materials Science and Engineering*, **134** pp 47-50.

[12] Xuedao Shu, Sutao Han, Jie Wei. The effect of the length of the shaft end on the quality of the optical axis end face of the stepped shaft forming by cross wedge rolling. 2018, *Engineering Science and Technology*, **50** (2) pp 177-183.