J. Y. YUAN, B. S. SUN, X. CHEN, H. L. MA, X. S. GAO, X. D. SHU

ISSN 0543-5846
METABK 61(2) 332-334 (2022)
UDC / UDK 621.775:669.3-513.4:531.78:531.23:518.1=111

# EFFECT OF PROCESS PARAMETERS ON THE FORCE PARAMETERS IN WARM SKEW ROLLING OF COPPER BALL

Received – Primljeno: 2021-09-03
Accepted – Prihvaćeno: 2021-10-30
Original Scientific Paper – Izvorni znanstveni rad

In order to better control the forming quality of copper ball by warm skew rolling process, a Finite Element Model (FEM) of copper ball warm skew rolling for the coupling of thermal and mechanical was established. The influence of process parameters on force and rolling torque was analyzed by using single factor research method. The results show that the smaller the cross angle, the lower the rolling temperature, the slower the rolling rotation speed, the greater the forming force and rolling torque, the more difficult for forming. The optimum rolling temperature is 600 °C; the optimum cross angle is 2,5°; the optimum rolling rotation speed is 60 rpm.

*Keywords:* copper ball, warm skew rolling, force, rolling torque, FEM

## INTRODUCTION

As one of the key raw materials for copper plating of Printed Circuit Board (PCB), copper ball has an important influence on the plating quality of PCB, such as uniformity and reliability. The performance of copper ball depends highly on the forming method. Comparing with tradition method such as forging, cutting and casting, the skew rolling technique has a lot of advantages. For example, high productivity, saving materials and energy, low cost and good working environment. High quality copper balls can be obtained by the process of warm skew rolling [1].

In recent years, many scholars have done a lot of research on the ball's formation by skew rolling. Pater et al [2,3] discussed multi-wedge helical rolling processes for producing steel balls and predicted the distribution of effective strain, temperature and effective stress of steel balls. Hu et al [4] carried out a study on the rolling force in the skew rolling process of phosphorous copper ball in order to improve single productivity and get parameters of phosphor copper ball rolling to provide a basis for the designing of mill.

In this paper, a new numerical model for the skew rolling process of copper ball under warm temperature is developed by using Simufact 14.0 simulation software. It is of great significance to explore the influence of process parameters on the force parameters of copper ball, which is mainly reflected in the efficient production of copper ball by warm skew rolling, the lightweight design of the skew rolling mill, and the control of rolling forming quality.

J. Y. Yuan, B. S. Sun, X. Chen, H. L. Ma, X. S. Gao, X. D. Shu. Ningbo University, School of Mechanical Engineering and Mechanics, Ningbo, China; B. S. Sun (Email: sunbaoshou @nbu.edu.cn)

## MATERIAL AND FEM SIMULATION OF WARM SKEW ROLLING

In the design of the roll, the diameter of the roll is 180mm. The main parameters involved in the design process are shown in Table 1. In order to ensure the accuracy of simulation, the design of roller is particularly important. In this design, the lofting function of the modeling software Creo is firstly used to get the expansion diagram of the required pass surface as shown in Figure 1(a). Then the required roller model was obtained by annular bending of the pass surface, as shown in Figure 1(b). Compared with the method of fitting the surface by curve constructor, this scheme is faster and easier to modify.

This research uses C11000 pure copper that provided in Simufact v.14 software as the material of the billet. The expression of its constitutive relationship is as follows [5]:

$$\dot{\varepsilon} = e^{22,788}\left[\sinh\left(0{,}01329\sigma_p\right)\right]^{6,002}\exp\left(-\frac{260\ 529}{RT}\right) \quad (1)$$

where $\dot{\varepsilon}$ is the plastic strain rate; $\sigma_p$ is the peak stress; R is the gas constant, and T is the temperature.

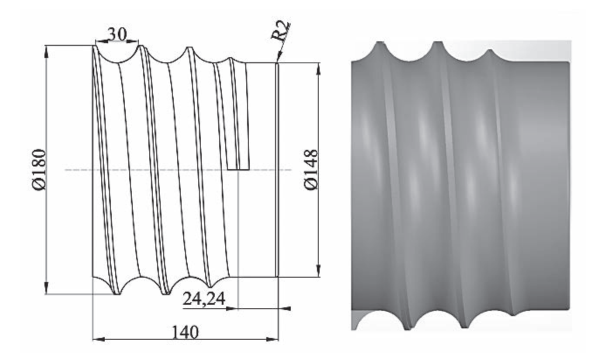


**Figure 1** An expansion of a pass surface and Dimensional model drawing of roller

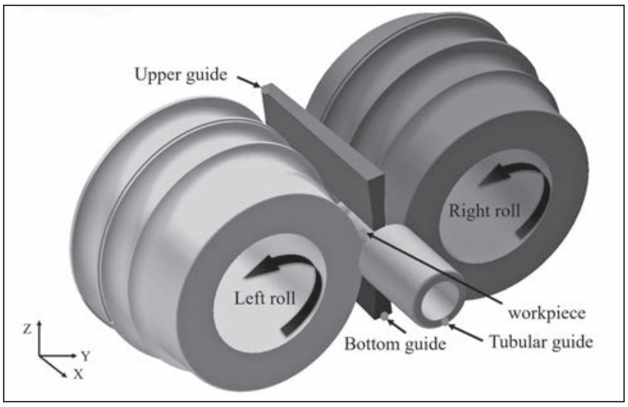


**Figure 2** FEM for warm skew rolling simulation

Table 1 **Main process parameters for simulation**

| Cross angle β/° | Rotation speed n/Rpm | Rolling temperature T/C° |
|---|---|---|
| 2,5/3/3,5/4/4,5 | 60 | 500 |
| 3 | 40/60/80/100/120 | 500 |
| 3 | 60 | 400/450/500/550/600 |

The above 3D geometric assembly model based on Creo platform were imported into Simufact 14.0 simulation software through STL format, and the simulation model of copper ball temperature skew rolling process as shown in Figure 2 was established. The model is composed of two rollers with the same rotation speed and direction, two guide plates up and down, feeding barrel and copper ball.

Warm skew rolling is a complex and time-consuming process, so it is necessary to set and simplify the finite element model reasonably. (1) The roller, guide plate and feeding barrel were set as rigid body, and the workpiece is set as plastic body. (2) The shear friction model was used between the workpiece and each die. The shear friction value between the workpiece and the roll was 0,9 and the shear friction value between the workpiece and the guide plate and the feeding barrel is 0,2. (3) Hexahedral mesh was used, with an average mesh unit of 1,2 mm. About 45500 elements were used in billet modeling. (4) The billet temperature is set at 500 C°, and the two rollers and other moulds were set at 100 C°. The 15 groups of single factor experiment parameters are shown in Table 1.

## EFFECT OF PROCESS PARAMETERS ON THE FORCE PARAMETER

Figure 3 shows the maximum force and rolling torque at different cross angle. As shown in the Figure 3, when the cross angle increases from 2,5° to 4,5°, the maximum rolling force increases with the increase of cross angle, corresponding values for each cross angle are 36,93 KN, 38,01 KN, 40,17 KN, 41,28 KN and 43,57 KN respectively. The main reason for this phenomenon is that the increase of roll Angle will make the axial extrusion of roll-on bar more intense, so the maximum rolling force also presents a rising trend. It shows that the proper decrease of roll Angle is more beneficial to the forming of copper ball in the roll pass cavity. The

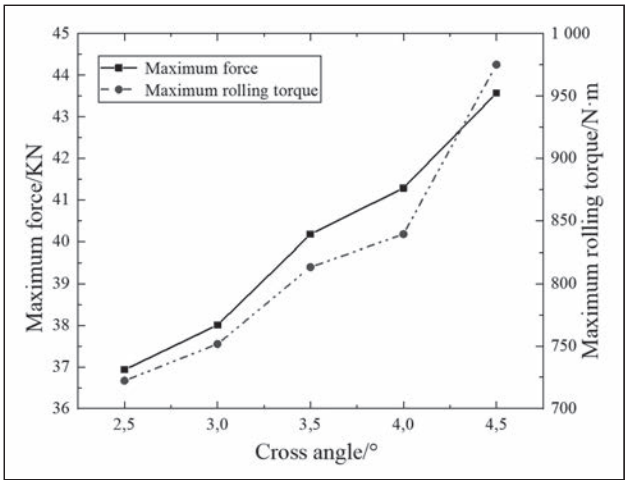


**Figure 3** Maximum force and rolling torque at different cross angle

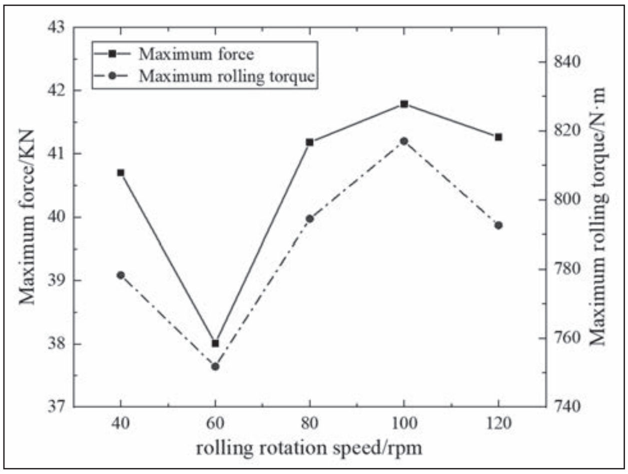


**Figure 4** Maximum force and rolling torque at different rolling rotation speed

maximum rolling moment can be used to measure the stability of copper ball cross rolling process. It is not difficult to see from the figure that with the increase of roll inclination Angle, the maximum rolling moment values are 722,32 N·m, 751,77 N·m, 813,33 N·m, 839,15 N·m and 975,10 N·m, respectively, showing an increasing trend with the increase of roll inclination Angle.

Through the above analysis, it can be found that reducing the roll Angle can effectively reduce the rolling force and rolling moment in the process of copper ball pass cross rolling. Therefore, on the premise of guaranteeing the forming quality, smaller roll Angle should be selected to be more conducive to the forming of copper ball.

Figure 4 shows the maximum force and rolling torque at different rolling rotation speed. It is not difficult to see from the figure that when the roller speed increases from 40 rpm to 60 rpm, the maximum rolling force decreases from 40,70 KN to 38,01 KN. The main reason is that the increase of the roller speed will cause the friction heat effect between the roller and the bar material to increase the temperature of the material and soften the material to a certain extent. The forming is easier and the deformation resistance is reduced. When the roll speed increases from 60 rpm to 100 rpm, the maximum rolling force increases greatly from 38,01 KN to 41,79 KN. The main reason is

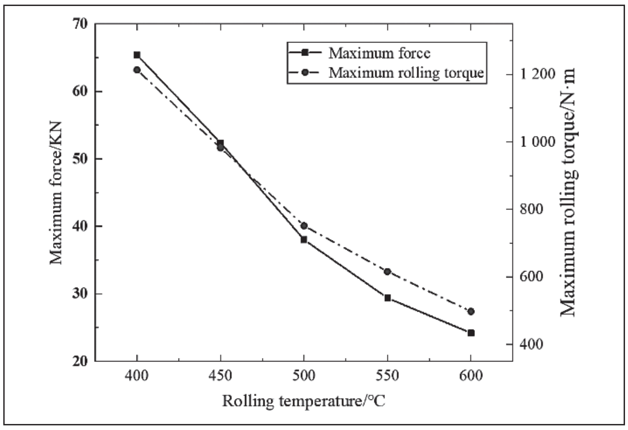


**Figure 5** Maximum force and rolling torque at different rolling temperature

that in this speed range, the continuous change of roll speed makes the edge pressure drop per unit time doubled and the deformation rate of bar in the cavity significantly increased. The resulting work hardening will increase the deformation resistance of the bar. When the roll speed increases from 100 rpm to 120 rpm, the maximum rolling force decreases slightly from 41.79 KN to 41.27 KN under the influence of friction heat effect and work hardening.

With the increasing of roll speed, the maximum rolling moment values corresponding to different roll speed are 778,28 N·m, 751,77 N·m, 794,49 N·m, 817,01 N·m and 792,58 N·m, respectively, which firstly decreases, then increases and finally decreases with roll inclination Angle. Through the above comprehensive analysis, it can be found that the roll speed has little influence on the rolling force and energy parameters at each stage, and there is no obvious fluctuation. By analyzing the variation of maximum rolling force and rolling moment with roll speed, it can be seen that the influence of roll speed on the peak value of force and energy parameter is the result of friction heat effect and work hardening. It shows that choosing the right roll speed needs to consider many factors comprehensively. In this paper, when the roll speed is 60 rpm, the rolling force and rolling moment are significantly reduced.

Figure 5 shows the maximum force and rolling torque at different rolling temperature. When the rolling temperature gradually increases from 400 C° to 600 C°, the corresponding maximum rolling forces are 65,37 KN, 52,37 KN, 38,01 KN, 29,38 KN and 24,20 KN, respectively. The maximum rolling force decreases greatly with the increase of rolling temperature. The main reason is that in the process of copper ball pass cross rolling, the increase of rolling temperature will enhance the plastic of the material, the metal fluidity of the material is obviously enhanced, and the deformation resistance of the forming process is significantly reduced. With the increasing of rolling temperature, the maximum rolling moment values corresponding to different rolling temperature are 1213,5 N·m, 982,41 N·m, 751,77 N·m, 616,13 N·m and 497,77 N·m, respectively.

It shows a decreasing trend with rolling temperature. Through the above comprehensive analysis, it can be found that the rolling temperature has a significant influence on the rolling force and energy parameters at each stage of pass cross rolling, and there is an obvious range fluctuation. By analyzing the variation of the maximum rolling force and rolling moment with the roll speed, it can be seen that the increase of rolling temperature is obviously beneficial to reduce the deformation resistance during the forming process, and the metal fluidity is significantly improved, indicating that the copper ball rolling temperature should be appropriately increased on the premise of guaranteeing the forming quality of copper ball.

## CONCLUSIONS

The following conclusions can be drawn from the simulation:

Cross angle, rolling rotation speed and rolling temperature will all have an impact on the force parameter. The force and rolling torque increase with the increases of cross angle, decreases firstly then increases with the increases of the rolling rotation speed, and decreases with increases of the rolling temperature.

The influence of process parameters on force and rolling torque was analyzed by using single factor research method. The optimum rolling temperature is 600°C; the optimum cross angle is 2,5 °; the optimum rolling rotation speed is 60 rpm.

## Acknowledgements

We gratefully acknowledge that the project was supported by National Natural Science Foundation of P.R. China (Grant No. 51975301) and by Ningbo Scientific and Technology Plan Project (grant number: 2020Z110) Ningbo Beilun District Science and Technology Innovation Team (grant number: 2020BL0003). The work was also sponsored by K. C. Wong Magna Fund in Ningbo University.

## REFERENCES

[1] F. L. Mao, Y. H. Shuang, Q. H. Wang, F. J. Wang, Y. J. Gou, C. J. Zhao, Theoretical and Experimental Study of the Tandem Skew Rolling Process, Steel Research International 89 (2018) 8,1800022.

[2] Z. Pater, Numerical analysis of helical rolling processes for producing steel balls, International Journal of Materials and Product Technology 53 (2016)2,137-153

[3] Z. Pater, J. Tomczak, J. Bartnicki, M. R. Lovell, P. L. Menezes, Experimental and numerical analysis of helical-wedge rolling process for producing steel balls, International Journal of Machine Tools and Manufacture 67 (2013), 1-7,

[4] X. B. Hu, B. Y. Wang. Research on Rolling Force of Cross Rolling Phosphorus Copper Ball [J]. Forging and Stamping Technology 34(2009)3,75-77.

[5] J. Wang. Study on Microstructure of Pure Copper in Continuous Extrusion Process [Dissertation], Dalian: Dalian Jiaotong University, 2009.

**Note:** The responsible translator for English language is J. Y. Yuan, Ningbo, China