Research on Titanium Alloy Bar Based on Mathematics Model and Finite Element Simulation in Three-roll Tandem Rolling Process

Wang Chunxiang§, LIU Xinyu

Department of Mechanical Engineering, Anhui Technical college of Mechanical and Electrical
E-mail: §ahjdpanlu@126.com, bahjdluxinyu@126.com

Abstract: Three-roll mill is also called as Y-type mill, which provides a way to analyze hard metal. In this paper, the mathematics model of subtriangular piece in round triangle pass was proposed first. To verify the reasonableness of the process, finite element simulation was used to obtain the parameters in deformation process, such as contact arc length, contact width, the shape of rolling piece.

1. Introduction
Titanium alloy has the advantages of high specific strength, high temperature resistance and corrosion resistance. The forming methods of titanium alloy bar include casting, forging, rolling, extrusion and other plastic processing methods, and the production of small size bar is mainly rolling forming, such as three-roll mill.

Three-roll mill is also called as “Y-type” mill. Three-roll mill provides the technology of rolling without torsion and tension.[1]. The deformation in three-roll pass is equal, and spread is lower, which is less than 5%. In addition, the restriction of rolling piece is imposed from three directions by three rollers, which is propitious to low plastic, hard-deformed materials, such as titanium alloy and tungsten.

2. Mathematics model in deformation region of subtriangular piece in round triangle pass

For round triangle sequence pass system, subtriangular piece will enter the next round triangle pass, as shown in Fig. 1[2-3]. Ignoring spread, the contact points between subtriangular piece and round pass are $D, D'$. 

Table 1. Rolling parameters of subtriangular piece in round triangle pass

| Parameter                     | Value |
|-------------------------------|-------|
| Roller radius                 | $R$   |
| Round triangle Pass radius    | $r_1$ |
Similarly, the mathematics model of parameters in deformation region can be derivated with mathematics analytic method[4].

Contact arc length \( l = \sqrt{R^2 - \left(\frac{H_0}{2} - (R + r_i)\right)^2} \) (1)

Contact width \( k = \sqrt{3}r - \sqrt{r_i^2 - r^2} \) (2)

The maximum rolling reduction \( \Delta h_{\text{max}} = \frac{H_0}{2} - r_i \) (3)

The rolling reduction for every point for \( DQEND \) can be calculated by EQ. 4.

\[
\begin{align*}
\Delta h &= \begin{cases} 
\sqrt{\left(\frac{H_0}{2}\right)^2 - x^2} & x < 0 \\
\sqrt{3}x + 2r - \sqrt{r_i^2 - x^2} & x_D < x < x_D' 
\end{cases}
\end{align*}
\] (4)

Cross-section area \( S_h = \int_{x_D}^{x_D'} \Delta h \, dx = 2\int_{x_D}^{x_D'} \Delta h \, dx 
\]

\[
S = 2\left(\frac{\sqrt{3}r}{2}\right)^2 - 2\left(\frac{\sqrt{3}r}{2}\right)\left\{\frac{H_0}{2} - r_i - \sqrt{r_i^2 - r^2}\right\}
\]

\[
\left(\frac{\sqrt{3}r}{2}\right)^2 - 2\left(\frac{\sqrt{3}r}{2}\right)\left(r_i - \frac{H_0}{2} - \sqrt{r_i^2 - r^2}\right) + \frac{H_0^2}{4} - \frac{H_0}{2} \sin\frac{\pi x}{\pi} \right\} dx
\]

Mean rolling reduction in deformation region \( \bar{\Delta h} = \frac{S_h}{k} \)

Where, \( k \) :contact width

Contact area \( S_j = \left(\sqrt{3}r - \sqrt{r_i^2 - r^2}\right) \times \sqrt{R^2 - \left[\frac{H_0}{2} - (R + r_i)\right]^2} \) (6)

3. The parameters(contact arc length,contact width) of each pass in deformation process based on mathematics model

Based on the mathematics model of subtriangular piece in round triangle pass sequence in three-roll tandem rolling process, the parameters in deformation process were calculated first, such as contact arc length and contact width.[5-6]

Take pass system for \( \Phi 20-\Phi 10 \) titanium alloy rod (TC4) product line for example, the parameters in deformation region was calculated with mathematics model.

Based on the mathematics model, the parameters (contact arc length, contact width) of each pass in deformation process were calculated firstly, as shown in Table 2.
Table 2. Result of the parameters of each pass for Φ25~Φ12 titanium alloy rod

| Pass | 1   | 2   | 3   | 4   | 5   | 6   | 7   | 8   |
|------|-----|-----|-----|-----|-----|-----|-----|-----|
| Contact arc length (mm) | 32.1 | 27.10 | 29.08 | 21.03 | 25.33 | 20.67 | 25.45 | 20.87 |
| Contact width (mm)      | 17.45 | 11.04 | 14.06 | 7.65 | 11.29 | 7.88 | 10.08 | 5.69 |

4. Finite element analysis

The eight-pass sequence rolling process of Φ20~Φ10 titanium alloy rod (TC4) product line was shown in Fig. 2.

Fig.2 The finite element model of Φ25~Φ12 titanium alloy rod tandem rolling

5. Comparison between mathematics model and finite element simulation

5.1 Comparison of contact arc length between FEM simulation and mathematics model

Fig. 3 shows the shape of rolling piece at lengthwise contact for each pass of the eight-pass flat triangle-round triangle sequence pass system. And contact arc length of FEM simulation is shown in Table 2. [7-8]

As is shown in Table 3, error of contact arc length between FEM simulation and mathematics model was below 9%, and the contact arc length of mathematics model was smaller, as the result of ignoring the spread.
Table 3. Comparison between FEM simulation and mathematics model

| Pass | 1  | 2  | 3  | 4  | 5  | 6  | 7  | 8  |
|------|----|----|----|----|----|----|----|----|
| contact arc length with simulation (mm) | 32.76 | 28.48 | 30.55 | 21.64 | 24.87 | 20.15 | 25.14 | 21.58 |
| contact arc length with Mathematics model (mm) | 31.10 | 26.10 | 28.08 | 20.03 | 24.33 | 19.67 | 24.45 | 19.87 |
| Error (%) | 5.34 | 9.12 | 8.80 | 8.04 | 2.22 | 2.44 | 2.82 | 8.61 |

5.2 Comparison of contact width between FEM simulation and mathematics model

Based on FEM simulation, the shape of rolling piece at the entrance and the exit for each pass was obtained to calculate the contact width. Fig.4 shows the shape of rolling piece at the entrance and the exit for each pass.

![Shapes of rolling pieces](image)

As is shown in Table 4, error of contact width between FEM simulation and mathematics model was mainly below 4%, and the contact width of mathematics model was smaller, as the result of ignoring the spread.

Table 4. Comparison between FEM simulation and mathematics model

| Pass | 1  | 2  | 3  | 4  | 5  | 6  | 7  | 8  |
|------|----|----|----|----|----|----|----|----|
| contact width with simulation (mm) | 16.75 | 10.12 | 13.11 | 6.59 | 10.64 | 6.99 | 9.22 | 4.84 |
| contact width Mathematics model (mm) | 16.45 | 10.04 | 13.06 | 6.65 | 10.29 | 6.88 | 9.09 | 4.69 |
| Error (%) | 1.82 | 0.78 | 0.38 | -0.93 | 3.36 | 1.63 | 1.42 | 3.09 |

6. Conclusions

Based on both mathematics model and finite element simulation, the parameters in deformation process were obtained, such as contact arc length and contact width. The error between FEM simulation and mathematics model is reasonable, less than 10%, considering the influence of spread. Therefore, both mathematics model and finite element simulation can be used for the pass design of three-roll mill.

Acknowledgement

This work is supported by Anhui University natural science research project (No. KJ2018A0864).
References

[1] CAO xifa. KOCK wire and rod rolling mill and rolling theory (1)[J]. Steel rolling. 1999(4):28-37
[2] P Lu,L xinyu.Numerical model of round rod in flat triangle pass in three-roll tandem roll[J].Materials Science & Engineering Conference Series ( 2017), 191-197.
[3] Ito M, Owada S, Nishimura T, Ota T. Experimental study of coal liberation: electrical disintegration versus roll-crusher comminution. Int J Miner Process 2009;92(1–2):7–14.
[4] Powell MS, Morrison RD. The future of comminution modeling. Int J Miner Process 2007;84(1–4):228–39.
[5] HUANG Yi, XU Ke Kang, HAN Jing Qing, et al. Application of ADRC for aircraft attitude control[J]. Proceed 3rd Asian Control Conference, 2000:548-552.
[6] J.H.Min, H.C.Kwon, Y.Lee, J.S.Woo, Y.T.Im.Analytical model for prediction of deformed shape in three-roll rolling process[J]. Journal of materials processing technology.140(2003):471-477
[7] Kazutake Komori. Simulation of deformation and temperature in multi-pass three-roll rolling[J]. Journal of materials processing technology.92-93(1999):450-457.
[8] YANG Sheng Ming, SHUENN JENN KE. Performance Evaluation of a Velocity Observer for Accurate Velocity Estimation of Servo Motor Drives[C]. IEEE Transaction on Industry Application, 2000, 36(1):98-104.