Continuous extrusion and rolling forming of copper strips

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Abstract – Continuous extrusion and rolling technology was proposed as a new strip production technology. It conducts a hot rolling process using waste heat after continuous extrusion. The continuous extrusion and rolling forming was simulated with DEFORM-3D^T. Influences of extrusion wheel velocity and rolling reduction on the continuous extrusion and rolling forming were analyzed. It was shown that as extrusion wheel velocity increases, torque of extrusion wheel, chamber force and rolling force, will drop; temperature of the billet in the area of abutment which is highest will increase. As the rolling reduction is increased, torque of the extrusion wheel and force acting on the chamber decrease, while torque and force of the rolls increase. The experimental results showed that a homogeneously distributed and equiaxed grains microstructure can be formed in copper strip billets with an average grain size of about 80 μm , after continuous extrusion. Grains of the copper strips are stretched clearly, during rolling, along the rolling direction, to form a stable orientation. Nevertheless, the grain boundaries are still relatively clear to see.

Key words: Continuous extrusion and rolling, Copper strip, Numerical simulation, Rolling reduction

1. Introduction

Continuous extrusion and rolling forming technology is a burgeoning and environmental manufacturing technology. It is combined with continuous extrusion process and rolling process in a row. The principle of continuous extrusion and rolling process is that oxygen-free copper plates or strips is pressed in the groove of the extrusion wheel by coining wheel, and moves with the friction of extrusion wheel rotating, then is obstructed by the abutment, turns to the chamber. The billet fills the chamber until extruded from the die. The temperature of the strips from continuous extrusion is about 400–600 °C in the exit of die [1], there is a distance between continuous extrusion machine and rolling mill, and strips supplied by continuous extrusion could be rolled down until reaching a certain length with the temperature about 360–400 °C in the entrance of rolls.

Compared to traditional processes of cold rolling after continuous extrusion, the continuous extrusion and rolling process method has the following advantages [2–5]: (1) In this process, the frictional resistance for energy dissipation is transferred into the deformation driving force, and deformation heat and friction heat are used to reach the thermal deformation temperature of billet, so the heating process is eliminated; and (2) both the continuous extrusion and rolling completely achieve the thermal deformation of the billet, during which the dynamic

recrystallization occurs. Therefore, the grain is significantly refined and the material property is improved; however, the size of the billet is nearly the same as that of the finished product, thus reducing the workforce of the finishing process.

Yun et al. proposed the principle of continuous extrusion and rolling technology, based on theoretical calculation and numerical simulation [6]. But it did not consider the metal flow regularity in the process with variation of the technological parameter.

In this work, the finite element model of continuous extrusion and rolling process was established by using DEFORM-3D software platform in order to simulate the whole process, and the metal flow regularity was analyzed in the continuous extrusion and rolling process with variation of the technological parameter, such as the influence of extrusion wheel velocity, rolling reduction and strip size.

2. Numerical simulation of continuous extrusion and rolling

The DEFORM-3D software was used for the numerical simulation of continuous extrusion and rolling process of copper strips. The influence of extrusion wheel velocity and rolling reduction on the continuous extrusion and rolling forming process were analyzed. The temperature of billet, effective-stress of billet, torques of extrusion wheel and rolls, force of chamber, rolling force were compared and studied during forming.

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Figure 1. Cross-sectional shape of the rolled strip.

Figure 2. Finite element geometric model.

The size of a copper strip produced by continuous extrusion process is depicted in Figure 1.

The finite element simulation model which was established by using TLJ400 continuous extrusion machine and the roll with diameter of 250 mm as the model is depicted in Figure 2, where the representative geometry parameters are indicated. To save time and reduce the computer storage capacity, 1/2 of the integral model was used for the simulations based on the symmetry [7, 8].

In this work, the rigid viscoplastic finite element method was used. The billet was set as the rigid-plastic body, whereas the die and other parts were set as rigid bodies. The shear friction driving model was used for the friction between the contact surfaces of the billet and the die. All of the initial parameters in numerical simulation are shown in Table 1 [9–12].

3. Simulation results and analysis

3.1 Influences of the extrusion wheel velocity on the continuous extrusion and rolling forming

Extrusion wheel velocity was set to 6 r/min, 9 r/min, 12 r/min for the numerical simulations. Comparison of temperature, effective-stress, torque of extrusion wheel and rolling, force of chamber, and rolling force are analysed in different extrusion wheel velocity.

It can be observed that the temperature lines in the continuous extrusion and rolling process are escalating trend with extrusion wheel velocity increased in Figure 3. The temperature of billet in the area of abutment is hottest which was increased from 787 °C to 883 °C, temperature of billet in the area of chamber is ascended from 604 °C to 688 °C, temperature of billet in the area of exit of die is risen from 537 °C to 620 °C, and temperature of billet in the area of rolls is from

Table 1. The initial parameters of numerical simulation.

Condition	Value
Material of billet	Copper
Material of tool and die	AISI-H13
Diameter of billet (mm)	Φ20
Initial temperature of billet (°C)	20
Initial temperature of tool and die (°C)	450
Rotation velocity of extrusion wheel (rpm)	6, 9, 12
Friction factor of billet and extrusion wheel	0.95
Friction factor of billet and guide roller	0.05
Friction factor of billet and chamber and die	0.3
Friction factor of billet and roller	0.35
Conductivity of billet (N/s K)	30
Heat capacity of billet (N m ² /K)	0.3

Figure 3. Effects of velocities of extrusion wheel on temperature.

192 °C up to 206 °C. What makes increment of temperature of billet is that speed difference between billet and extrusion wheel become bigger with greater velocity of extrusion wheel, work from extrusion wheel to qualities of heat of billet is increased, extent of plastic transformation of billet is severer with extrusion wheel velocity increased. Due to temperature of billet in the continuous extrusion process is risen, the temperature in the rolling process is also increased, and the abutment and chamber will be suffered more abraded. As a result, it's not advisable to choose overlarge velocity of extrusion wheel for continuous extrusion and rolling process.

Figure 4 is depicted that effective-stress of billet is risen slightly since extrusion wheel velocity increased. As extrusion wheel velocity increased, temperature of billet is higher, flow velocity of billet is rapider, effective-stress is also ascended.

From Figure 5, it can be seen that the torque of extrusion wheel will be dropped from 5.44 N mm to 4.80 N mm when extrusion wheel is increased from 6 r/min to 12 r/min, which because increase of temperature of billet makes extent of plastic transformation of billet severer, work of billet to plastic transformation needed from extrusion wheel is reduced.

Because of resistance of strip suffered by rolls decreasing, torque of rolls is also dropped from 16.08 N mm to 12.96 N mm with extrusion wheel increased 6 r/min to 12 r/min (Figure 6).

It can be figured out, from Figures 7 and 8, that the values of force of chamber and rolling force lines are all falling trend with extrusion wheel velocity increased. The value of force of

Figure 4. Effects of velocities of extrusion wheel on effective-stress.

Figure 7. Effects of velocities of extrusion wheel on force of chamber.

Figure 5. Effects of velocities of extrusion wheel on torque of extrusion wheel.

Figure 8. Effects of velocities of extrusion wheel on rolling force.

Figure 6. Effects of velocities of extrusion wheel on torque of roll.

chamber is dropped from 3.89×10^5 N to 2.92×10^5 N, which as a result of resistance power of plastic transformation of billet is reduced as temperature of billet risen. And value of rolling force is decreased from 1060 kN to 804 kN. We can draw a conclusion that rolling process will become easy with rapider velocity of extrusion wheel, but the rapider velocity of extrusion wheel, the higher temperature of billet in the

process, the higher temperature of abutment, the less working life of the moulds.

3.2. Influences of the rolling reduction on the continuous extrusion and rolling forming

The value of rolling reduction is one of the most important parameters in the process of continuous extrusion and rolling. In this part, transformation regularity of the size of strips will be discussed which are presented by continuous extrusion and the size is 120×10 mm². The rolling reduction respectively are 2 mm, 4 mm, 6 mm, 8 mm.

Figure 9 depicts temperature of billet is decreased when rolling reduction is increased. The temperature of billet in the area of abutment is hottest which is dropped from 822 °C to 813 °C, temperature of billet in the area of chamber is fell from 650 °C to 629 °C, temperature of billet in the area of exit of die is descended from 585 °C to 563 °C, and temperature of billet in the area of rolls is from 206 °C down to 187 °C.

Owing to temperature of billet in the continuous extrusion decreased, effective-stress of billet in the area of exit of die is increased in Figure 10. However effective-stress of billet in the area of rolls is dropped, because resistance power from rolls to

Figure 9. Effects of rolling reduction on temperature.

Figure 12. Effects of rolling reduction on force of chamber.

Figure 10. Effects of rolling reduction on effective-stress.

Figure 13. Effects of rolling reduction on torque of roll.

Figure 11. Effects of rolling reduction on torque of extrusion wheel.

Figure 14. Effects of rolling reduction on rolling force.

billet is reduced as reduction decreased, which makes billet flow harder and more slowly.

It can be obviously observed that value of torque of extrusion wheel and force of chamber is declined at first, then ascended following in Figures 11 and 12. When rolling reduction is from 2 mm up to 4 mm, torque of extrusion wheel is descended from 5.47 N mm to 5.18 N mm, and force of chamber is from 4.79×10^5 N to 3.15×10^5 N. When rolling reduction is from 4 mm up to 8 mm, torque of extrusion wheel

is increased from 5.18 N mm to 5.70 N mm, and force of chamber is from 3.15×10^5 N to 4.83×10^5 N.

While value of torque and stress of rolls are risen accompanied by rolling reduction increased. Torque of rolls in Figure 13 is increased from 4.52 N mm to 18.36 N mm, as rolling reduction increasing from 2 mm to 8 mm. At the same time, force of rolls in Figure 14 are risen from 465 kN to 1148 kN. In other words, it is not suitable for rolling process to take overlarge rolling reduction, if not, service life of rolls will be influenced.

Figure 15. Experiment of continuous extrusion and rolling.

Figure 16. The billet.

4. Experiment

4.1. Experimental procedures

In the experiment, TLJ400 continuous extrusion machine and rolling mill with a diameter of 250 mm were used for continuous extrusion and rolling process, (Figure 15). The wheel speed was 5 rpm, the size of extrusion slab was 120 mm × 10 mm and the rolling reduction was 4 mm.

The specimens in extrusion wheel groove, deformation chamber, after extrusion and after rolling were taken out and prepared by wire cutting along the longitudinal direction. Metallographic specimens were corroded by compositing acid ($\text{FeCl}_3 + \text{HCl}$) after furbishing and polishing. Microstructures were observed under the OLYMPUS BX41M metalloscope.

4.2. Results and discussion

The billet of continuous extrusion and rolling exhibited typical casting structure of the upward as-cast copper rod with diameter $\Phi 20$ mm. The average size of grain was over 1 mm, the microstructure at the middle and adge is small equiaxed grains and oversize column crystal respectively (Figure 16).

Figure 17 shows the microstructure of copper after continuous extrusion forming. A homogeneously distributed and

Figure 17. Copper strips of continuous extrusion.

Figure 18. Microstructure of a copper strip.

equiaxed grains microstructure can be found in the copper strip billet with a grain size of about 80 μm .

Within the grains, twins can be observed clearly. These twins were annealing twins instead of deformation twins. This was because that copper is a face-centered cubic metal which symmetry is high. Copper has more slip systems and is easy to slip. It is difficult for copper to occur twinning in the deformation to produce deformation twins, except at very low temperature which is extremely hard to slip. The annealing twins is a kind of growing twins formed during grain growth. When the grains are grown by grain boundary migration, atomic layer stacking order of the grain boundary corner accidental wrong heap, there will be coherent twin boundaries, followed by the formation of annealing twins in the grain boundary corner. Stacking fault energy of copper is low and it is easy to form annealing twins [13].

The grains of the copper strip after rolling were stretched obviously along the rolling direction to form a stable orientation, but the boundaries were still relatively clear, as shown in Figure 18.

5. Conclusions

Based on the research conducted, the following conclusions may be drawn:

1. As the extrusion wheel velocity increases from 6 r/min to 12 r/min, torque of the extrusion wheel will be

reduced from 5.44 N mm to 4.80 N mm, force on the chamber dropped from 3.89×10^5 N to 2.92×10^5 N, and rolling force decreased from 1060 kN to 804 kN. Temperature of the billet in the area of abutment where the temperature is highest increases from 787 °C to 883 °C.

2. As the rolling reduction is increased from 2 mm to 8 mm, torque of the extrusion wheel descends from 5.47 N mm to 5.18 and force of the chamber from 4.79×10^5 N to 3.15×10^5 N, while torque of the rolls increases from 4.52 N mm to 18.36 N mm, and the force of rolls from 465 kN to 1148 kN.
3. A homogeneously distributed and equiaxed grains micro-structure can be formed in copper strip billets with an average grain size of about 80 μ m after continuous extrusion. Grains of the copper strip are stretched during rolling obviously, along the rolling direction, to form a stable orientation, and the boundaries are still relatively clear to see.

High-precision copper strips can be widely used in the fields like electronic materials, connectors, car terminals, coaxial cables, transformers, lead frames, and so on. Since continuous extrusion and rolling has obvious merits such as a short process chain, lower energy-consumption, higher quality, environmentally beneficial, and so on, it is certain that it will be used to replace traditional processes for producing copper belts. Therefore, it has excellent application prospects.

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