Process Design of Pilot Warm Rolling Mill for Difficult-to-deform Materials Research

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Abstract. Due to the increasing demands for warm rolling research of difficult-to-deform materials, the State Key Laboratory of Rolling and Automation of Northeastern University (NEU-RAL) developed a set of pilot warm rolling mill with its functions including: rolled piece heating online, rolls heating online, hydraulic screwdown, tension control and reversing rolling. The rolls heating uses induction heating mode and the rolled piece heating adopts direct resistance heating way. The warm rolling process is designed based on the characteristics of pilot warm rolling mill. The AZ31 magnesium alloy samples were rolled successfully and demonstrated that warm rolling is an effective method to process difficult-to-deform materials. The new pilot warm rolling mill has been successfully put into use in several research institutes of China, it will contribute further studying on warm rolling characteristics of difficult-to-deform materials.

1. Introduction

Warm rolling is suitable for processing some metals and alloys which have low plasticity and high deformation resistance under normal temperature conditions and are not suitable for cold rolling such as stainless steel, high carbon alloy steel and tool steel. Taking warm forming can make them work hardening eliminated and deformation resistance reduced[1-3]. Warm rolling is also used for processing metals and alloys that can be cold rolled but have low production efficiency, many rolling passes and high energy consumption, for example, magnesium alloys and high-strength aluminum alloys, etc. take use of warm forming to improve the plasticity and prevent cracking[4-6]. Those materials like tungsten, molybdenum, titanium, chromium, and alloys which are extremely difficult to be cold-deformed and are highly oxidized, inhaled and cracked during hot deformation, are also suitable for warm rolling[7-11].

When the off-line heated rolled piece is rolled in the cold rolling mill, the temperature drops sharply due to the contact heat conduction of the work rolls, so that the rolled piece temperature is in an uncontrollable state. Obviously, it is difficult to obtain reliable research results by offline heating to complete the experimental research on the warm rolling process. Therefore, researchers of difficult-to-deform materials are increasingly demanding the pilot warm rolling mill with online heating. In order to ensure the stability of the rolled piece temperature during the warm rolling process, the rolling process not only requires on-line heating of the rolled pieces, but the on-line heating of the rolls is also an important factor to ensure the temperature stability of the warm rolling process.

In order to provide suitable online heating experimental conditions for metallic material researchers, NEU-RAL designed an innovative warm rolling mill with straight pulling and reversing capability[12]. The design is based on pilot cold rolling mill by adding resistance heating device between both sides.
of the chucks and rolls (shown as figure 1) and induction heating device of the work rolls at the entrance of the mill (figure 2). It fulfills simultaneous online heating of rolled pieces and rolls and better meets the researches demands for the pilot warm rolling mill.

Fig.1. The heating device of rolled piece

2. Main equipment parameters and heating mode

2.1. Main equipment parameters
The main equipment of pilot warm rolling mill includes mechanical system, hydraulic system, rolls heated system, rolled pieces heated system, control system, data acquisition system. The control system includes heating system control, automatic gauge control (AGC), and automatic tension control (ATC)[13]. The main device parameters are as following:

(1) Rolls system: the backup rolls size $\Phi 550-530 \times 350$ mm, the work rolls size $\Phi 200-180 \times 370$mm.

(2) Mill form: single stand four-high reversing warm rolling mill, front and rear hydraulic tension control, maximum rolling force 4500kN.

(3) Screw down system: hydraulic screw down, AGC hydraulic cylinder stroke 80mm, screw down speed with load 0.2mm/s, screw down speed 6mm/s without load, positioning accuracy ±5μm.

(4) Rolling speed: 0~0.4~0.6m/s continuously adjustable.

(5) Hydraulic tension device: the thickness range of jaw clamping samples 0.2~6.0mm, the hydraulic cylinder stroke 2000mm, tension control range 1~50kN, positioning accuracy ±0.5mm.

(6) Rolled piece heated: direct resistance heating mode, heating power 180kW, maximum heating current 5000A. The surface temperature of the sheet is controlled between room temperature to 800℃.

(7) Work rolls heated: induction heating mode, the work rolls surface temperatures range are 100℃~250℃ adjustable.

Fig.2. The heating device of the work rolls

(1) Contact thermometer, (2) induction coil, (3) the upper work roll, (4) rolled piece, (5) the lower work roll, (6) induction coil, (7) chuck
2.2. The rolls heating
Heating rolls are achieved by induction heating method [14-16]. The induction heating technology is a unique non-contact heating method that converts electrical energy to magnetic field energy, then to electrical energy and finally to thermal energy. When the high-frequency alternating current passing through the electromagnetic induction device, the greater the coil current increases, the greater the magnetic flux it generates, and the induced electromotive force increases in the rolls. The eddy current becomes large, as a result, the Joule heating effect becomes more significant. Similarly, as the frequency of alternating current increases, the eddy current will raise and hysteresis effect will be strengthened.

The induction coils are installed between the work rolls and the support rolls, near the work rolls, up and down symmetrically. The heating rate of the rolls is controlled by controlling the magnitude and frequency of the AC current. The heating device of the work rolls is shown in figure 2.

2.3. The rolled piece heating
The resistance heating mode is used to heat the rolled piece [17]. The heating system consists of transformers, SCR(Silicon Controlled Rectifier), thermocouple thermometer, current transformer, electrode rod and the heating electrode. The heating electrodes are installed in the vicinity on both sides of the hydraulic chuck and roll. The heating system is divided into two parts through the contact point of the rolls and the sample as segmentation point. The closed-loop temperature control principle is shown in figure 3. The sample heating temperature is controlled by adjusting SCR conduction angle of the transformer primary side to control the current of transformer secondary side.

PLC(Programmable Logic Controller) calculates the resistance of the sample before heating starts and determines the given heating current to ensure the heating rate is set according to the different resistance value. PLC compares the actual temperature and the set temperature of the human-machine interface to control the SCR conduction angle through the PID (Proportion Integration Differentiation) control module to achieve closed-loop temperature control.

![Fig.3. The closed-loop temperature control principle of rolled piece heating](image)

3. Process design of warm rolling

3.1. Process requirements
(1) The pilot warm rolling mill is used in difficult-to-deform materials of cold rolling such as high silicon steel, magnesium alloy, iron alloy, stainless steel and so on.
(2) The rolled pieces are limited in the following sizes(thickness×width×length, mm).
   Incoming size: (4.0~6.0)×(200~250)×450; Finished size: (0.3~1.0)×(200~250)×(≤2000)
(3) The work rolls are heated before heating rolled piece since heating the rolls is slower. The rolls are taken to ensure the creep mode when heating the rolls to avoid local overheating that burns the rolls.

(4) Because the rolled piece becomes easy to deform after heating, the mill is required to ensure proper tension to prevent breaking the belts.

(5) The mill control system should have accurate and reliable controlling capabilities for the rolling process and have precise detection capabilities to ensure the reliability, accuracy and reproducibility of experimental data to lay the foundation for carrying out high-level research.

3.2. The process design of warm rolling

3.2.1. Preparation before rolling

Firstly the operator inputs PDI(primary data input) data of the samples to the database via data acquisition system. The PDI data are automatically sent to monitor screen HMI(Human Machine Interface) to be confirmed by the operator after the experiment starts. The process control computer calculates rolling schedule based on PDI data. The operator chooses a computer pre-computed schedule or an experienced schedule according to the actual situation, ensures that the left and right side tension cylinder of the mill, the roll gap instruments of operating side and drive side are in place, and sets the rolling status to an appropriate mode (automatic, semi-automatic, manual) on operating panel.

3.2.2. Rolling process

The rolling process is shown in figure 4.

Step 1. Heating the roll. The roll is heated to the set temperature while keeping the roll to rotate at a low speed.

Step 2. Loading the sample. Stop heating the roll and stop rotating the roll. Put one side of the sample into the chuck of the tension cylinder at the mill entrance side and keep clamping. Open the roll gap to the desired position. Operate the tension cylinder of the entrance side forward slowly until the sample has crossed the mill and the cylinder has reached the limit. Operate the tension cylinder of the export side forward near the sample and clamp the other side of the sample with chuck.

Step 3. Establishing tension. First set both sides tension value through HMI, then adjust the roll gap to the desired position, the tension cylinder on both sides are switched to the closed-loop tension control mode after the rolls have contacted with the sample and rolling force has produced.

Step 4. Heating the sample. Set the heating temperature for each pass on HMI. Start the heating function into the closed-loop temperature control mode. Begin to roll when the sample's temperature reaches set value.

Step 5. Rolling. Adjust the roll gap to set value then start rolling, and stop rolling automatically when one side tension cylinder reaches the limit. After that the sample is heated to set temperature of the next pass and adjust the roll gap and tension to finish next pass rolling.

Step 6. Unloading the sample. Remove the tensions on both sides after finishing rolling, lift the roll gap, loose one side chuck of the tension cylinder, withdraw the sample from the roll gap by moving the other tension cylinder, then release chuck, remove the sample. The rolling is over.

Step 7. Processing experimental data. The data acquisition system will collect data via the PLC system in rolling process, record data to the database and generate data reports. The operator can query historical data through ID, view and print the data report.
3.3. The warm rolling experiment

(1) Experimental purpose: Study the warm rolling process of magnesium alloy.

(2) Experimental materials: AZ31 magnesium alloy.

(3) Experimental method: Select two samples of AZ31 magnesium alloy with the dimensions of 4×175×1000mm. The rolling target thickness is 2mm. The sample No. 1 uses the process of only heating the sample and not heating the rolls. The sample No. 2 uses the process of heating the rolls to 180℃. The others setting of two samples are the same as shown in table 1.

| Pass | Set gap (mm) | Sample temperature (℃) | Rolling speed (m/s) | Set tension (kN) |
|------|--------------|-------------------------|--------------------|-----------------|
| 1    | 3.80         | 300                     | 0.15               | 3.5             |
| 2    | 3.35         | 300                     | 0.17               | 3.5             |
| 3    | 3.00         | 300                     | 0.19               | 3.4             |

(4) Results and Analysis. The results are shown in figure 5, the No. 1 sample was broken after rolling a pass, the flat shape looked like a washboard, and the rolling cannot be completed properly; the No. 2 sample was rolled successfully, the sample surface was smooth and the thickness was uniform. The comparison results show that, if the rolls were not heated, the temperature of the rolled piece dropped so much that rolling cannot be finished normally because of the role of heat conduction between the rolls and the sample.
Fig.5. Warm rolling results of AZ31 magnesium alloy

4. Conclusion
(1) A pilot warm rolling mill was developed with the functions of rolled piece and rolls simultaneously heated on line, which was used to study rolling process for the difficult-to-deform materials.

(2) The warm rolling process was designed based on the pilot warm rolling mill.

(3) The warm rolling experiments of AZ31 magnesium alloy show that the rolls heating are as important as the rolled piece heating for sheet warm rolling.

(4) The new pilot warm rolling mill has been successfully put into use in several research institutes of china, making a contribution for further study on the warm rolling characteristics of difficult-to-deform materials.

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