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ARTICLE

Dynamic Contact Heat Transfer Mechanism of Magnesium Alloy Strip by Rolling Process Simulation

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Abstract: By ameliorating the contact heat transfer measurement device and simulating the transient heat exchange characteristics of roll gap by finite element model, the coupling influence of temperature, pressure, and roughness on the contact heat transfer coefficient was analyzed. Results show that there are two obvious critical thresholds for the contact heat transfer. When the interface pressure is less than 22.1 MPa at temperature<150 °C, there is a good linear relationship. When the interface pressure exceeds the first threshold, the contact heat transfer is significantly enhanced, presenting the obvious nonlinear characteristic. In addition, once the interface pressure exceeds 50 MPa and the temperature is higher than 300 °C, the contact heat transfer quickly tends to be stable. Obviously, the second threshold is directly related to the elastic-plastic deformation of friction peaks on the surface of magnesium alloy strip. The contact heat transfer at high pressure is caused by the increased micro-contact area and the interactive diffusion of friction peak. Based on these characteristics of the phenomena, it is beneficial to accurately control the contact temperature of roll gap, and therefore to design suitable rolling parameters and optimize the rolling technique.

Key words: contact heat transfer coefficient; magnesium alloy strip; dynamic heat conditions; transient temperature; rolling process

Magnesium alloy has excellent properties, but its application is restricted by the deformation during the rolling process[1–2]. Temperature is an important influence factor in the plastic deformation[3]. However, complex heat exchange conditions on the surface of magnesium alloy affects the temperature distribution, and the appropriate temperature range can be hardly controlled[4]. Therefore, some effective methods have been proposed, such as hot rolling (HR), warm rolling (WR), equal diameter angular extrusion, asynchronous rolling, cross rolling, and electric plastic rolling[5–6], which are all related to the temperature control during the deformation of magnesium alloy. Obviously, the heat exchange condition of contact interface is crucial, which directly affects the distribution characteristics of temperature field, deformation quality, and deformation efficiency of rolled magnesium alloy[7–10]. Particularly, the transient temperature change needs to be controlled accurately in the processing process[11–12].

The transient temperature field of interface in the actual rolling process can hardly be detected[13], even by the heat balance equation with measured rules[14]. Because the heat transfer effect contributes to the whole deformation process of AZ31 alloy[15], the temperature fields of magnesium alloy strip often show uneven features, resulting in complex deformation defects[16]. Therefore, the interfacial heat transfer coefficient under different temperature fields should be investigated[17–18]. Based on physical mechanism of heat transfer, Xiao[19], Pan[20], and Huang[21] et al proposed the online heating rolling technology of magnesium alloy to improve the mechanical properties, which can reduce the edge crack and the twins of AZ31 alloy[22]. The heat transfer process has an important influence on the stress status and the microstructure by changing the constitutive relationship of magnesium alloy[23–30]. As the key influence factors for the rolling process of magnesium alloy strip, the essential characteristics between temperature change and deformation have been widely researched. Ma et al[31] discussed the relationship between the online temperature and edge crack. Moreover, the temperature gradient caused by the heat transfer always results in some

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edge cracks of strip, thereby restricting the further deformation[32]. Therefore, the heat transfer process should be further studied to accurately control the transient temperature field[33].

For the temperature control, the contact heat transfer coefficient (CHTC) is a critical parameter in the heat transfer process[34]. Particularly, the precision forming largely depends on the accurate control of CHTC[35–40]. The solid heat transfer is efficient and complex due to the interface and pressure[41–42]. Unfortunately, because of the heat transfer mechanism and thermal conductivity, the heat transfer can be hardly measured and can only be modeled by the static heat transfer coefficient[43]. Therefore, Sun et al[44] proposed the solution algorithm to solve the inverse equation of heat conduction. Chen et al[45] measured the interfacial heat transfer coefficient (IHTC) between AZ91D alloy and the quartz sand mold by the inverse method. Zhang et al[46] established the empirical equation between IHTC and local pressure/solidification temperature on the casting surface based on the multiple linear and polynomial regression. Wu et al[47] considered the changes of actual contact area and the thickness of oil film, and discussed the oxide scale effect of extruded metal on the interface heat transfer. Nam et al[48] transformed the equivalent thermal conductivity, which was a function of thickness, temperature, and pressure, into the developed coil model. Chen et al[49] proposed that the accurate simulation results of temperature field and stress field of magnesium alloy can only be obtained by the correct surface heat transfer coefficient. Cebo-Rudnicka et al[50] proposed the distribution variation of heat flux or the heat transfer coefficient on the cooling surface with time. Bazhenov et al[51] obtained the relationship between IHTC and ingot surface temperature by the error function with suitable materials to provide the high cooling rate. Wang et al[52] used the inverse method based on mold internal temperature measurement to determine IHTC at the metal mold interface. Le et al[53] studied the temperature of AZ31B plate during the air-cooling transportation under different thicknesses and initial temperatures, and proposed that the preheating temperature should be increased before the air cooling. Xiong et al[54] proposed a boundary setting model based on the heat transfer coefficient. Wang et al[55] constructed the functional relationship between the fracture trajectory and the stress state/temperature/rolling direction of AZ31 alloy. Therefore, CHTC is the key factor for calculation and prediction model of actual heat transfer conditions. Particularly, in the practical rolling process, the complex boundary conditions seriously affect the temperature distribution due to CHTC, which leads to inaccurate deformation or prediction error. Thus, it is necessary to analyze the dynamic CHTC according to the actual rolling process to obtain good deformation and product quality of magnesium alloy strip.

The dynamic contact conditions and mechanical mechanism of CHTC should be thoroughly investigated. The interface temperature of rolling gap has a direct influence on the deformation of magnesium alloy strip because of CHTC. However, the dynamic contact heat transfer mechanism of rolling process is rarely reported. Because the ideal physical experiment is very different from the actual rolling process, large prediction deviation exists. In addition, the accurate temperature prediction of rolling process by the dynamic heat transfer mechanism should be conducted. Obviously, CHTC measurement is important for the temperature field model under special conditions. CHTC measurement device should be designed to simulate the actual rolling process. Besides, the key parameters should be set according to the practical rolling parameters. CHTC simulation can provide accurate temperature prediction for the whole rolling process of magnesium alloy strip. Therefore, in this research, the dynamic heat transfer mechanism of rolling process was researched by the improved CHTC measurement device.

1 Experiment

1.1 Process analysis

Temperature is crucial to the forming process of magnesium alloy. In the rolling process of ultra-thin magnesium strip, obvious heat conduction occurs: the hot magnesium strip is in contact with the cold rolls, but the real-time temperature cannot be obtained. In order to accurately obtain the deformation mechanism of magnesium strip, the deformation resistance should be determined according to the real-time temperature, reduction rate, and deformation rate. Obviously, during the specific rolling process, the transient temperature can hardly be determined. In addition, for the thin magnesium strip, the thermocouple cannot be used for measurement. Thus, the mathematical model for “soft” measurement prediction was used. The precise heat transfer coefficient of rolling process can improve the prediction accuracy of mathematical model for alloy strips.

The contact heat transfer is the most uncertain parameter for the actual rolling process with high-speed rotation, which contains the air cooling and the water cooling in one rotation cycle. Therefore, the real-time calculation is conducted to obtain the equivalent heat transfer coefficient of contact cooling, air cooling, and water cooling. In the actual production process, the spraying is conducted only at the mill inlet to protect surface quality of magnesium strip. The cooling effect can also be improved by the spraying at the mill outlet or switching the rolling direction. In addition, the thin magnesium alloy strip is subjected to upper and lower cold rolls, and the heat exchange process is completed instantly, which results in a very high heat transfer coefficient. Moreover, the thinner the magnesium alloy strip, the larger the overall temperature drop.

The coefficients of air cooling, water cooling, and contact cooling are h_a, h_w, and h_c, respectively; the proportions of affected areas of air cooling, water cooling, and contact cooling are γ_a, γ_w, and γ_c, respectively. Thus, the equivalent heat transfer coefficient h_e is as follows:

$$h_e = \zeta_e(\gamma_a h_a + \gamma_w h_w + \gamma_c h_c) \quad (1)$$

where ζ_e is the deviation correction coefficient for real-time adaptive adjustment in the closed-loop control process. The air cooling and water cooling coefficients are basically fixed under specific conditions. However, the contact heat transfer is directly related to the transient temperatures of magnesium strip and rolls, which results in the error between the calculated and actual temperatures. Therefore, the accurate predicted temperature is important to the practical rolling process of magnesium strip. Obviously, h_c is the key factor, which is beneficial to obtain the relatively accurate prediction value of equivalent heat transfer coefficient and can improve the stability of magnesium strip rolling process.

Practically, CHTC fluctuates more obviously than the stable thermal conductivity does, i. e., it is difficult to determine CHTC under complex rolling conditions. Therefore, the influence of heat transfer by the physical mechanism should be investigated not only by experience but also through data regression. During the actual measurement, two axially insulated specimens are in contact under different loads. In addition to the axial heat conduction, assuming that the heat flow does not transfer to the surrounding environment, the stable uniaxial heat flows can be formed. In order to reduce the influence of complex working conditions on the detection accuracy, the contact heat transfer measurement device was designed and established by uniaxial steady-state heat flow[40,56]. Accurate CHTC could be obtained through one-dimensional heat conduction equation[57], namely the ideal one-dimensional heat conduction[58–59]. According to the equidistant temperature gradient of two specimens, the axial heat flow and the contact interface temperature difference were obtained. Based on the actual rolling process and the ideal heat exchange mechanism, some special heat transfer rules were obtained by the designed heat device. The influence of different pressures, roughness, and temperatures on the heat transfer coefficient was investigated to provide suitable adjusting factor for the rolling process of magnesium strip.

Firstly, several holes were drilled along the axial direction of the hot side (AZ31B alloy) and the cold side (9Cr2Mo alloy), and the corresponding armored thermocouple was inserted to collect the corresponding node temperature T_i (i=1, 2, ..., 8) with $T_1>T_2>...>T_0>...>T_8$ (T_0 is interface temperature). As shown in Fig.1, the heat of the hot side from the furnace is q_{in}, and the heat at the cold side is q_{out}. For more accurate simulation of the actual rolling heat transfer process, more thermocouples were used to improve the linearity, and the side thermocouples were close to the contact surface as much as possible. Therefore, the transient surface temperature change could be clearly observed, and the rolling gap could be simulated. Moreover, because the practical magnesium strip is very thin, the roll gap is approximately regarded as a plane, especially when the severe elastic flattening occurs in the rolling process of ultra-thin strips.

1.2 Practical process

To obtain CHTC rules, a special device was designed to study the influence of pressure and roughness on CHTC, and the process parameters were similar to those from the actual rolling process, as shown in Fig.2. The experiment parameters of surface roughness, average interface temperature, and interface stress are listed in Table 1. The surface roughness of 9Cr2Mo alloy was fixed, AZ31B alloys with different surface roughness were used to investigate the effects of different interface temperatures and interface stresses on CHTC. To ensure the experiment accuracy, each test was conducted at least three times.

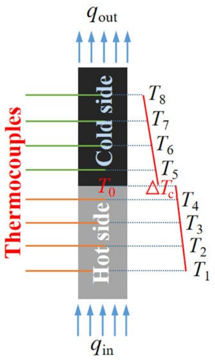

Fig.1 Schematic diagram of measuring points of thermocouples

1.3 Calculation process

Reducing the spacing or variable step size, or even adopting the non-spacing differential compensation can improve the measurement accuracy. Firstly, x axis was set as the heat flow direction when the first thermocouple was set as the base point. Thus, the temperatures T_i and T_j (i, j=1, 2, ..., 8) at corresponding positions of x_i and x_j could be expressed, respectively. Secondly, the interface temperatures at hot side and cold side were set as T_0^+ and T_0^-, respectively. Then, the interface temperature difference was $\Delta T_c = T_0^+ - T_0^-$.

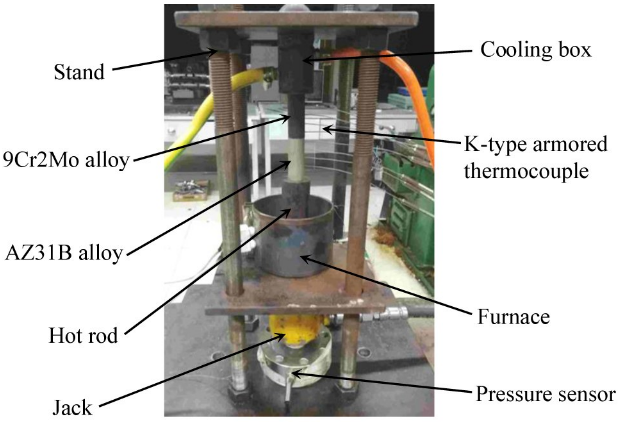

Fig.2 Appearance of designed measurement device

Table 1 Experiment parameters

Surface roughness of AZ31B alloy/μm	Average interface temperature/°C	Interface stress/ MPa
0.372	200	2.3
2.219	250	10.6
3.949	300	22.1

Therefore, the axial heat flux q_{ij} of any two points can be obtained by Fourier law of heat conduction, as follows:

$$q_{ij} = \lambda_{ij} \frac{T_i - T_j}{x_j - x_i} \tag{2}$$

where λ_{ij} (i, j=1, 2, ..., 8) is the average thermal conductivity between two measuring points. Assuming that the thermal conductivity of 27 W·m^{-1}·°C^{-1} of 9Cr2Mo alloy does not change with temperature, the variations of thermal conductivity coefficients of AZ31B alloy with temperature are shown in Table 2[60].

In order to minimize the influences of external radiation and heat dissipation, the average heat flow q_{avg} on the interface is as follows:

$$q_{\text{avg}} = \frac{q_{34} - q_{56}}{2} \tag{3}$$

According to the heat flux from T_3 to T_4, the heat flux from T_4 to the contact surface can be calculated, as follows:

$$q_{40} = q_{34} = \lambda_{34} \frac{T_3 - T_4}{x_4 - x_3} = \lambda_{40} \frac{T_4 - T_0^+}{x_0 - x_4} \tag{4}$$

Then, the temperatures on both sides of the interface can be obtained, as follows:

$$T_0^+ = T_4 - \frac{\lambda_{34}(x_0 - x_4)(T_3 - T_4)}{\lambda_{40}(x_4 - x_3)} \tag{5}$$

$$T_0^- = T_5 + \frac{\lambda_{56}(x_5 - x_0)(T_5 - T_6)}{\lambda_{55}(x_6 - x_5)} \tag{6}$$

Therefore, CHTC (h_c) can be accurately calculated, as follows:

$$h_c = \frac{q}{\Delta T_c} = \frac{q_{\text{avg}}}{T_0^+ - T_0^-} \tag{7}$$

Considering the actual rolling process, the main influence factors of CHTC are the rolling pressure and roughness. When the temperature of work roll and magnesium alloy strip is the same, the special influence mechanism of pressure and roughness on CHTC can be observed and quantitatively analyzed. When the pressures are different, the contact area varies obviously because a large number of friction peaks are flattened. Similarly, the high roughness of roll or magnesium strip can also result in the same effect. Therefore, the actual CHTC can be obtained and the conversion of equivalent heat transfer coefficient is achieved. After the friction heat, deformation heat, or other internal heat sources are calculated, the coupling temperature field model of rolls and magnesium alloy strips can be established, which provides accurate theoretical stress for the rolling model.

2 Results

2.1 Influence of surface roughness on CHTC

During the actual rolling process, the morphology of friction peaks changes obviously under different rolling pressures and roll roughness. For the ultra-thin strips, the friction peak morphology mainly affects the heat transfer process. In order to analyze the contact states of actual rolling gap, it is assumed that the roll roughness is fixed as 0.6 μm, and the roughness of AZ31B alloy in the first, second, and third pass is 0.374, 2.219, and 3.949 μm, respectively. CHTC variations under different interface temperatures and roughness are shown in Fig. 3. Generally, by softening or flattening the friction peaks, obvious linear features can be observed at low temperatures (<250 °C). However, once the temperature exceeds the critical temperature, CHTC is increased significantly due to the plastic deformation of almost all friction peaks. The interface temperature plays an important role on the roll roughness, which further increases CHTC. Conversely, CHTC variation leads to significant temperature deviations of alloy strip in the rolling process. Therefore, the roughness and CHTC should be jointly considered to ameliorate the actual rolling process of magnesium alloy strip.

Table 2 Thermal conductivity coefficients of AZ31B alloy with different temperatures[60]

Temperature/°C	−100	0	100	200	300	400
Thermal conductivity coefficient/W·m^{-2}·°C^{-1}	88	92	101	105	109	113

The influence of pressure on the friction peak is also significant. At high temperatures, a large number of friction peaks are flattened due to the plastic deformation, which results in the increase in contact area in the interface. The influence of roughness on CHTC is insignificant because the roughness of as-rolled strip is similar to the roll roughness. However, for the rolling with lubrication, CHTC should be analyzed based on the lubricant characteristics.

2.2 Influence of pressure on CHTC

The effect of pressure on CHTC of the interface at different temperatures was investigated. As shown in Fig. 4, when the pressure is less than 25 MPa, the relationships between the pressure and CHTC are basically linear. The higher the temperature, the more obvious the linearity. However, when the temperature exceeds 250 °C, CHTC is rapidly increased due to the increased contact area, which is caused by the numerous flattened friction peaks. Obviously, this variation trend is similar to that caused by roughness. At low pressure, CHTC is lower than that at high pressure even with high temperature condition. CHTC is high at high pressures. It is

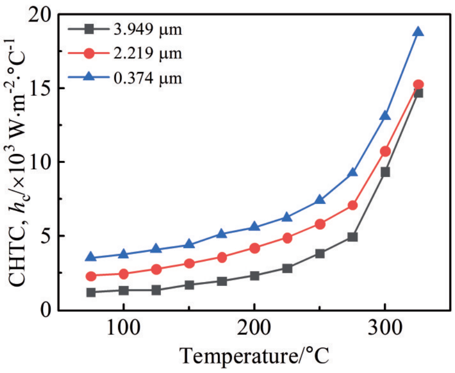

Fig.3 CHTC variation under different interface temperatures and roughness

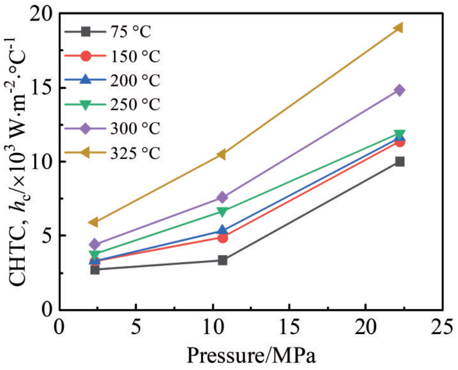

Fig.4 CHTC variation under different interface temperatures and pressures

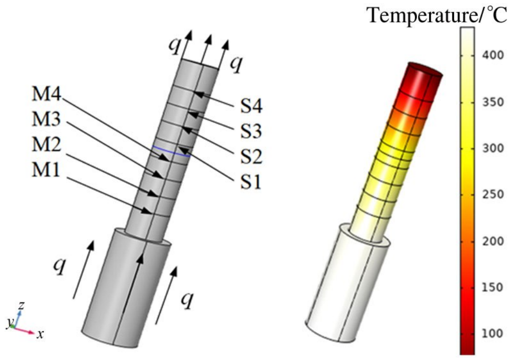

Fig.5 Schematic diagrams of COMSOL finite element model of CHTC under high pressures

inferred that a critical threshold may exist. However, the experiment at even higher pressures cannot be conducted because the magnesium alloy specimens will be crushed. Because the alloy strip withstands high pressure under high temperature in the actual rolling process, different phenomena or rules may occur, which requires further investigation on the characteristics of contact heat transfer in the actual rolling process.

When the interface pressures are 2.3, 10.6, and 22.1 MPa, CHTC is increased slowly with increasing the temperature from 75 °C to 150 °C, i.e., when the interface pressure is less than 22.1 MPa at temperature<150 °C, there is a good linear relationship. Once the temperature exceeds this critical range, CHTC is increased rapidly with increasing the pressure due to the fast flattening of numerous friction peaks. Particularly, when the temperature is 250−325 °C, the increasing rate of CHTC is obviously improved with increasing the interface temperature and plastic deformation of friction peaks. It can be seen that CHTC is not directly proportional to the interface temperature. Because the increase in actual contact area leads to the easy heat flow through the contact surface, the increasing rate of CHTC is gradually improved. Under the condition of thermal-mechanical coupling, with increasing the interface temperature under continuous stable load, mutual diffusion occurs at the interface. With the diffusion proceeding, the contact tightness of interface becomes more and more obvious, which can better promote the heat exchange. When the pressure exceeds 22.1 MPa, the higher the temperature, the more the increment in increasing rate of CHTC. When the temperature exceeds 250 °C, the deformation resistance of friction peaks decreases sharply, resulting in rapid increase in CHTC.

3 Simulation of CHTC Under High Pressure

3.1 Finite element modeling

COMSOL finite element model was established to simulate the contact heat transfer features under higher pressures, which is close to the actual rolling process. The simulation model was established according to the parameters of high-pressure experiments. As shown in Fig.5, M1−M4 and S1−S4 points represent the mounting holes of thermocouples in the AZ31B rod and the steel rod, respectively. The thermal insulation condition was adopted, and there was no heat radiation along the circumference of the specimen. Therefore, the heat flow was uniformly transferred along the axial direction. In addition, the convective heat flux was set on the upper surface of 9Cr2Mo alloy rod, which was cooled by the cooling water with flow rate of 0.1 m/s as the external convective. Under these thermal contact conditions, the contact surface roughness, interface pressure, gap thermal conductivity, and the radiant thermal conductivity were investigated.

3.2 Simulation results

Based on the finite element model, complex or extreme working conditions were simulated to provide accurate CHTC and reasonable deformation temperature range for the rolling process of magnesium strips. The contact interface pressures are 1.5, 20, and 50 MPa, which are close to the actual rolling pressure. In the actual rolling process, the pressure of roll gap is always higher than 50 MPa due to the continuous work hardening of magnesium alloy strip. To obtain good deformation, the temperature of magnesium alloy strip should be increased. However, the heat transfer under different pressures varies, which seriously affects the temperature field of roll gap. It is known that the actual situation is different from the ideal assumption due to the difficulty in real-time measurement. Based on the simulated results, the interface temperature difference is gradually decreased with increasing the pressure. Fig. 6 and Fig. 7 show the variation trends of CHTC at high pressures. Although these variation trends are different from those based on the actual rolling process, CHTC characteristics can be obtained by quantitative analyses. It is important to establish the applicable theoretical model for real-time prediction of temperature, because the deformation of magnesium alloy strip is very sensitive to the rolling temperature.

Overall, the simulated CHTCs under low pressures are basically consistent with the measured ones. Inevitable deviation exists due to the environment difference and the fact that the thermocouple cannot be infinitely close to the interface. Besides, the actual heat transfer has a little effect on

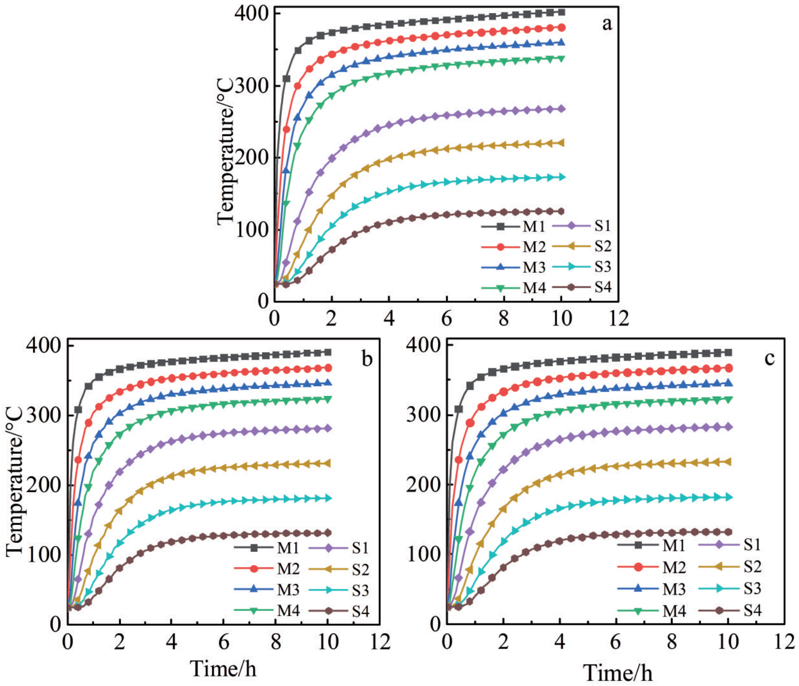

Fig.6 Temperature variations under different interface pressures: (a) 1.5 MPa, (b) 20 MPa, and (c) 50 MPa

CHTC. According to Fig. 7, the simulated results agree better with the actual rolling results under high pressures. When the interface pressure exceeds 20 MPa at 300 °C, CHTC obviously increases due to the ideal contact conditions. After the friction peaks are flattened at pressure>50 MPa, the heat exchange occurs instantaneously, which results in the large CHTC. Unfortunately, it is impossible to measure CHTC of roll gap in the actual rolling process. Therefore, CHTC can only be inversely calculated based on the change of real-time temperature. In addition, the coupling effect of air cooling and water cooling should also be considered, which results in the complex heat transfer mechanism. In the actual production, CHTC of roll gap can be calculated based on the abundant practical rolling data. The experiment results show that when the interface temperature is 200–250 °C, the friction peaks on the contact surface of AZ31B alloy strip present elastic deformation, and the actual contact area is increased with increasing the pressure, thereby improving CHTC. Meanwhile, when the temperature is 300 °C and the pressure is more than 50 MPa, the friction peaks already suffer plastic deformation. After the heat preservation, the plastic deformation of the friction peaks reaches the maximum degree. At this moment, when the temperature difference at the interface is the minimum, the thermal resistance of heat flow through the contact surface also reduces to the minimum, leading to the gradually stable CHTC.

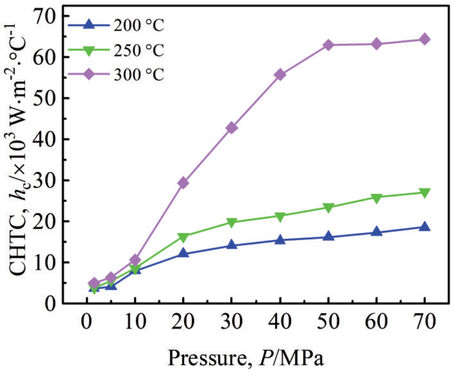

Fig.7 CHTC variations of AZ31B alloy strip under different interface temperatures and pressures

4 Analysis of CHTC in Actual Rolling Process

The ultra-thin magnesium alloy strip can hardly be rolled due to its high brittleness and anisotropy. Thus, the temperature control is a key factor in magnesium alloy rolling, which significantly influences the deformation quality and reduction rate. The thinner the strip, the more important the temperature control. Over-fast heat dissipation leads to the obvious temperature drop, which is important in the rolling process of magnesium alloy strip. Obviously, in addition to its own heat dissipation, the contact heat transfer is the most crucial factor affecting the temperature of roll gap. When the rolling speed is slow, the contact duration of interface is long, and then the significant temperature drop occurs. When the magnesium alloy with high temperature touches the cold rolls, its temperature is decreased sharply by the contact heat transfer, which results in the clear edge cracks. Meanwhile, the surface oxide film of AZ31B alloy is formed instantly by the high temperature burst and adhered to the surface of cold rolls, which leads to inferior surface quality of alloy strip. Fig. 8b shows the actual temperature change in the whole rolling process by the measurement results from thermo-

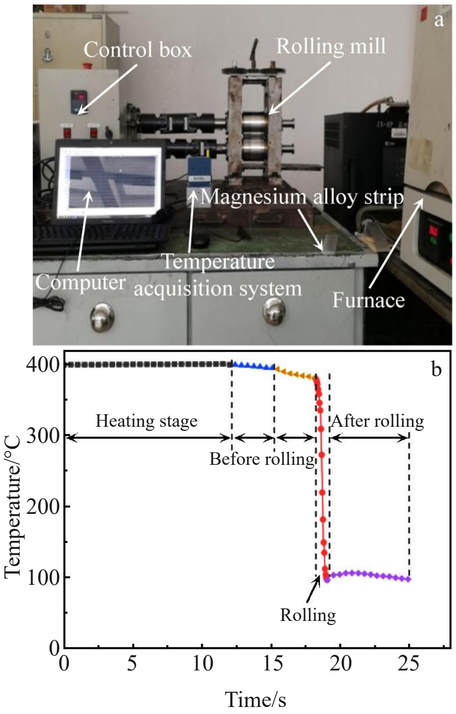

Fig.8 Appearance of equipment for rolling temperature measurement (a); temperatures of magnesium strip in rolling process (b)

couples on the surface of magnesium alloy strip.

In the practical rolling process, magnesium ally strip is usually heated to higher than 225 °C to obtain good plastic deformation. When the roll temperature is too low, a remarkable temperature drop occurs due to the rapid contact heat transfer. As shown in Fig. 9, when the initial thickness of AZ31B alloy is 2.0 mm, the measured temperature is obtained under the reduction rate of 20%. There are four stages in the rolling process. Firstly, the magnesium alloy strip with good plasticity is heated to 400 °C in the furnace. Secondly, before rolling, the temperature drop of 20 °C within 5 s occurs at the mill entrance due to the air cooling. In this stage, the temperature decreases slowly at first and then drops quickly. Then, in the rolling process, the temperature sharply decreases to about 100 °C within 0.2 s because of CHTC. After rolling, although the temperature rises a little bit due to the internal heat conduction, this increment can be neglected. Based on these results, the contact heat transfer is obvious when the thin magnesium alloy strip touches the cold rolls, leading to the rapid reduction in plasticity. Meanwhile, significant oxide film is formed due to the high temperature, and obvious edge cracks occur because of the sharp temperature drop, as shown in Fig. 9a. It can be concluded that the hot roll with constant temperature, online hot rolling by electromagnetic induction heating, and the electro-plastic rolling are all beneficial to the rolling deformation of magnesium alloy strip.

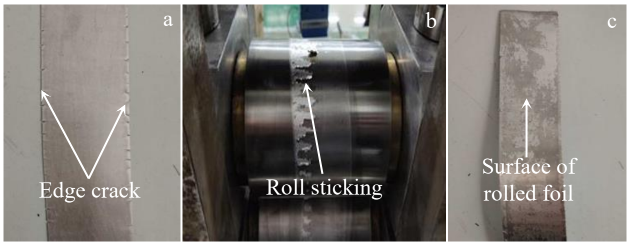

Fig.9 Appearances of rolling defects of magnesium alloy strip: (a) edge cracks, (b) roll sticking, and (c) rolled foil

5 Conclusions

1) Temperature is important to the rolling deformation of magnesium alloy strip, and the contact heat transfer directly determines the deformation temperature in the rolling process, which becomes an obstacle to the efficient preparation of magnesium alloy strip. Therefore, the accurate control of deformation temperature is crucial in magnesium alloy rolling. The contact heat transfer coefficient (CHTC) is important in the temperature roll gap.

2) When the interface pressure is less than 22.1 MPa at temperature<150 °C, there is a good linear relationship. The high pressure increases the contact area of interface by flattening the friction peaks. The linear relationship is obvious at high temperatures. However, once the pressure exceeds the critical value (22.1 MPa), the influence of high temperature on CHTC becomes more obvious, especially when the temperature is more than 250 °C.

3) Under low pressure (25 MPa), the simulated CHTC variation is similar to the measured one. However, when the pressure is above 25 MPa, CHTC increases significantly, and it tends to be stable when the pressure is more than 50 MPa. At this time, the deformation of friction peaks reaches the maximum degree, i.e., the theoretical contact area is close to the actual value.

4) In the actual rolling process, CHTC is important to the deformation temperature, which seriously affects the efficiency and quality of magnesium alloy strip. This research provides guidance for the accurate temperature control of roll gap by the real-time adjustment of rolling parameters based on CHTC.

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模拟轧制过程的镁合金带材动态接触传热机理

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摘　要：改进接触传热测量装置，利用有限元模拟镁合金轧制过程辊缝界面的瞬态换热特性，以准确分析温度、压力和粗糙度对接触传热系数的耦合影响。结果表明，接触传热存在2个明显的临界阈值。当温度在150 ℃以下且界面压力低于22.1 MPa时，存在良好的线性规律。当超过第一阈值后，接触传热明显增强，呈现显著的非线性特征。另外，当界面压力超过50 MPa（第二阈值）且温度超过300 ℃时，接触传热很快趋于稳定。显然，此时的第二阈值与镁合金带材表面摩擦峰的弹塑性变形直接相关，通过增加微接触面积和摩擦峰的交互扩散，从而形成高压接触传热。基于这一现象的规律特征，有助于精确控制辊缝的接触界面温度，便于设计合适的轧制参数或优化轧制工艺。

关键词：接触传热系数；镁合金带材；动态边界条件；瞬态温度；轧制过程

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