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Full length article

Effect of driver roll rotational speed on hot ring rolling of AZ31 magnesium alloy

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Abstract

Based on the ABAQUS/Explicit code, A 3D elastic–plastic and coupled thermo-mechanical FE model of radial ring rolling of AZ31 Magnesium alloy has been proposed to analyze the influence of rotational speed of driver roll to study the inhomogeneity distribution of strain and temperature, fishtail coefficient, rolling force parameters. The results show that: (1) when the rotational speed of driver roll n increases, the strain distribution of the rolled ring becomes less homogeneous, and the temperature distribution more homogeneous yet, and leading to an optimal n value; (2) the fishtail coefficient firstly decreases, then increases with the increase of n; (3) the rolling force, contact area and rolling moment gradually descend with the increase of n.

Keywords: Rotational speed of driver roll; AZ31 magnesium alloy; FEM; Ring rolling

1. Introduction

Ring rolling is widely used in the production of railway tires, anti-friction bearing races, flanges of various geometry and rings of different materials and dimensions used in the chemical, aerospace, automotive and nuclear industries. During hot ring rolling, the feed rate of drive roller plays a significant role in ring quality control, because different feed rate of drive roller will generate different radial feed, which has considerable influence on the shape and size, accordingly influence on the uniformity of strain and temperature distribution (STD) which is in close relation to microstructure of ring and ring's mechanical property. Therefore it is necessary to research the effect of feed rate of drive roller in hot ring rolling.

Up to now, there are lots of studies on hot ring rolling. For instance developed a coupled thermo-mechanical model of the deformation processes occurring, simulation analysis of the ring rolling process [1,2]; reveals the impact of the drive roller speed on the ring rolled strain, temperature, microstructure evolution and inhomogeneous deformation [3,4]; Analysis the driven roller speed of the ring forming process on fishtail coefficient, spread, rolling force, rolling torque and deformation field [5]; study the effects of blank size and roll size on uniformity of strain and temperature distributions during hot rolling [6–9]. These works contributed to the rapid development of ring rolling, however,in terms of previous works, there are few ones cover the hot ring rolling of magnesium alloys.

In this paper, based on the ABAQUS/Explicit code, A 3D elastic–plastic and coupled thermo-mechanical FE model of radial ring rolling of AZ31 alloy has been proposed to analyze

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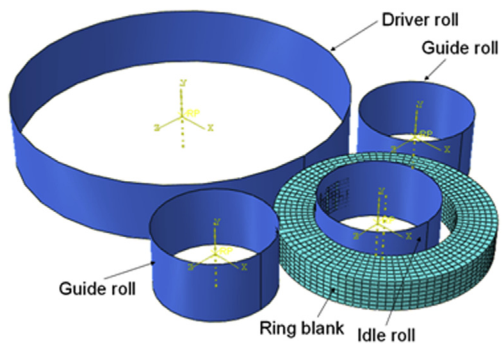


Fig. 1. Coupled thermo-mechanical 3D FE model of AZ31 alloy hot ring rolling.

the influence of rotational speed of driver roll on the non-uniform distribution of strain and temperature, fishtail coefficient of rolled ring and rolling force and power parameters.

2. FE modeling

Based on the ABAQUS/Explicit platform, A 3D elastic–-plastic and coupled thermo-mechanical FE model of radial ring rolling was builded. Ring rolling the drive roller, the core roll and the guide roller relative to the deformation of the deformation of the ring is very small, so the drive roller, the core roll and the guide roller is disposed to a rigid body, the ring member is set into a variable shape. As shown in Fig. 1, in order to prevent mesh distortion, using the re-meshing model, the ring is divided into 4410 uniform grid. The ring material is AZ31 alloy, its density is 1780 kg/m^3, Poisson's ratio is 0.35, and thermal expansion coefficient is 2.6E-5. The thermal caducity, specific heat, Young's modulus and their temperature dependence are from Ref. [10]. In order to study the impact of driving roller speed on ring rolling, select $n = \{19.1, 28.7, 38.2, 47.8, 57.3, 66.9\}$, (r/min), the simulation conditions are summarized in detail in Table 1.

3. Evaluation indicators

3.1. SDT and SDP

The standard deviation of equivalent plastic strain and temperature of the rolled ring are employed to evaluate the inhomogeneity. The larger SDP and SDT are, the more uniform of the ring strain and temperature, the more nonuniform of the microstructure of the rolled ring, and the worse mechanical property is. SDP and SDT are defined respectively as Ref. [11]:

$$\mathrm{SDP} = \sqrt{\sum_{i=1}^{N} (\mathrm{PEEQ}_i - \mathrm{PEEQ}_a)^2 / N} \quad (1)$$

$$\mathrm{SDT} = \sqrt{\sum_{i=1}^{N} (\mathrm{NT11}_i - \mathrm{NT11}_a)^2 / N} \quad (2)$$

where FEEQ is the equivalent plastic strain, FEEQ_i is the FEEQ of the node i, $\mathrm{PEEQ_a} = \sum_{i=1}^{i=N} \mathrm{PEEQ}_i / N$ is the average FEEQ of the all nodes, N is the sum of the nodes, NT11 is the node temperature, NT11i is the NT11 of the node i, $\mathrm{NT11_a} = \sum_{i=1}^{i=N} \mathrm{NT11}_i / N$ is the average NT11 of the all nodes.

3.2. Fishtail coefficient

Uneven plastic deformation of the radial rolling appear axial end surface of the fishtail shape shown in Fig. 2. The fishtail coefficient (F_t) is an important indicator to measure the quality of end, the less fishtail coefficient is, the better quality of the end-plane of the rolled ring is, and the more homogeneous deformation in axial direction of the rolled ring is. The fishtail coefficient is defined as

$$F_t = \frac{B_{max} - B_{min}}{B_0} \quad (3)$$

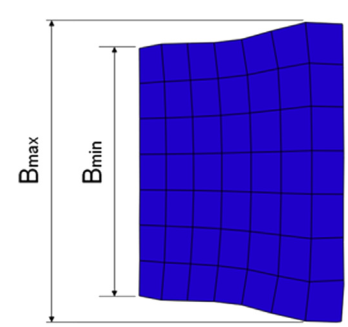


Fig. 2. The axial spread of the rolled ring.

Table 1
Ring rolling process parameters involved in the simulation.

Process parameters	Value	Process parameters	Value
Radius of driver roll (mm)	104.8	Temperature of driver roll (°C)	100
Radius of idle roll (mm)	34.9	Temperature of left guide roller (°C)	100
Radius of guide rolls (mm)	31.9	Temperature of right guide roller (°C)	100
Axial height of ring blank (mm)	20	Temperature of ring blank (°C)	400
Thickness reduction (mm)	6.23	Feed rate of idle roll (mm/s)	2
Outer radius of ring blank (mm)	61.915	Friction coefficient	0.3
Inner radius of ring blank (mm)	39.685	Contact heat conductivity (W m^{-2} C^{-1})	6000
Temperature of environment (°C)	20	Convection coefficient (W m^{-2} C^{-1})	40
Temperature of idle roll (°C)	100	Emissivity	0.7

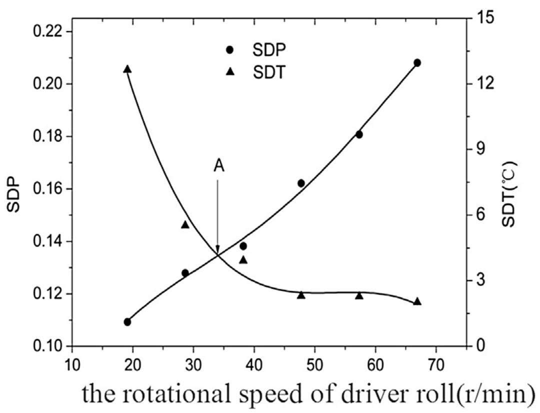


Fig. 3. Effect of drive roll feed on plastic strain and temperature.

where B_0 is the initial axial height of ring, B_{max} is the maximum of axial height of rolled ring, and B_{min} is the minimum of axial height of rolled ring.

4. Results and discussion

4.1. Effect of the driver roll speed on plastic strain and temperature

Fig. 3 illustrates the effect law of the *n* on SDP and SDT. From Fig. 3, it can be discovered that the SDP increases gradually, and the SDT decreases gradually. That is to say, the strain distribution becomes less homogeneous and the temperature distribution becomes more homogeneous as the *n* increases. The rotational speed of the intersection A is the corresponding optimal rotational speed.

Fig. 4 shows the equivalent strain distribution of rolled ring. From Fig. 4, As the driver roll rotational speed increases, the ring shaped maximum and minimum strain while increasing strain, the maximum strain increases dramatically increase than the minimum strain substantially large; forming the inner and outer ring and the central surface strain increases while large, but the outer surface than the inner surface of the larger rate of increase, while the central minimum rate of increase, so that the molded ring strain distribution more uniform. This can be explained by the following aspects: firstly, when the *n* increases, the radial feed amount per revolution reduction, reduction in volume of metal deformation, it is harder for the plastic deformation zone to penetrate the ring from the surface to middle region; secondly, the larger *n*, ring speed is also increased, and the longer rolling time, leading to surface strain accumulation; thirdly, the larger *n*, the line speed of ring increases, the larger deformation and the more heat generation, meanwhile, the shorter rolling time and the lees heat loss, resulting in the higher temperature of the ring, so it is easier for material to flow. The synthetic effects of the above factors cause the deformation more uniform.

Fig. 5 shows the temperature distribution of rolled ring, From Fig. 5, As the drive roller speed increases, the ring shaped maximum and minimum temperature while increasing, the minimum temperature increases dramatically increase than the maximum temperature substantially large, the temperature difference becomes smaller, the temperature distribution of the ring forming becomes more uniform. This can be explained by the following aspects: firstly, when the *n* increases, the temperature of ring surface increasing; secondly, the larger *n*, the radial feed amount per revolution reduction, reduction in volume of metal deformation, the heat distribution becomes more uniform.

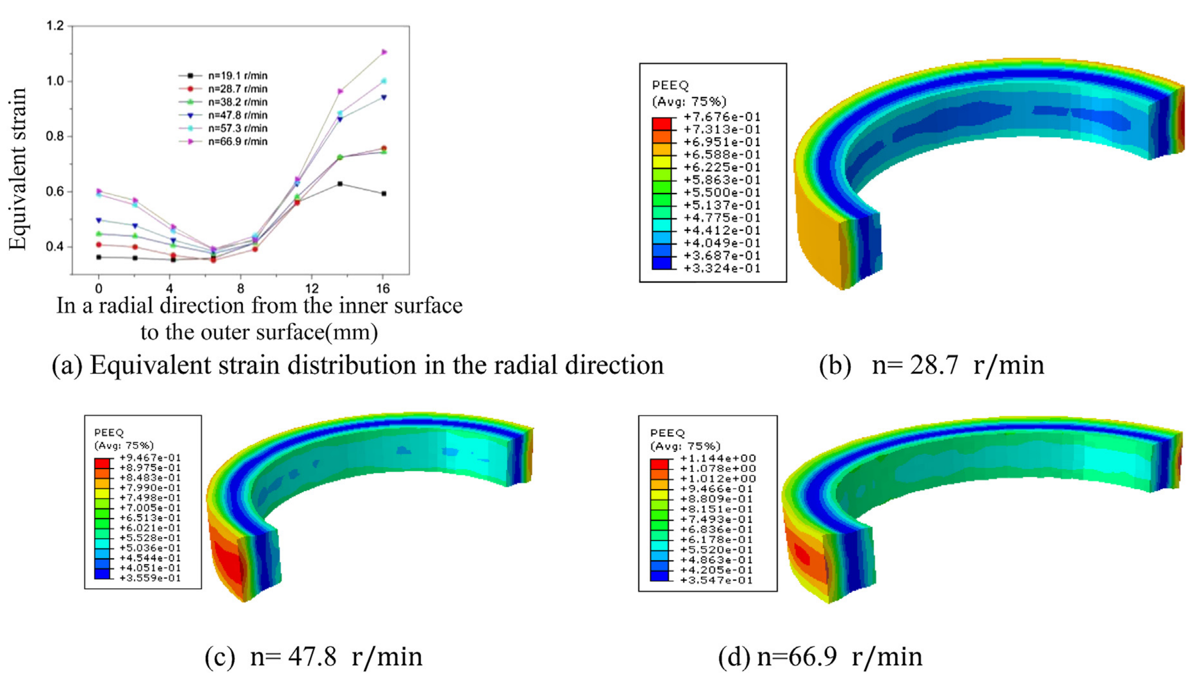
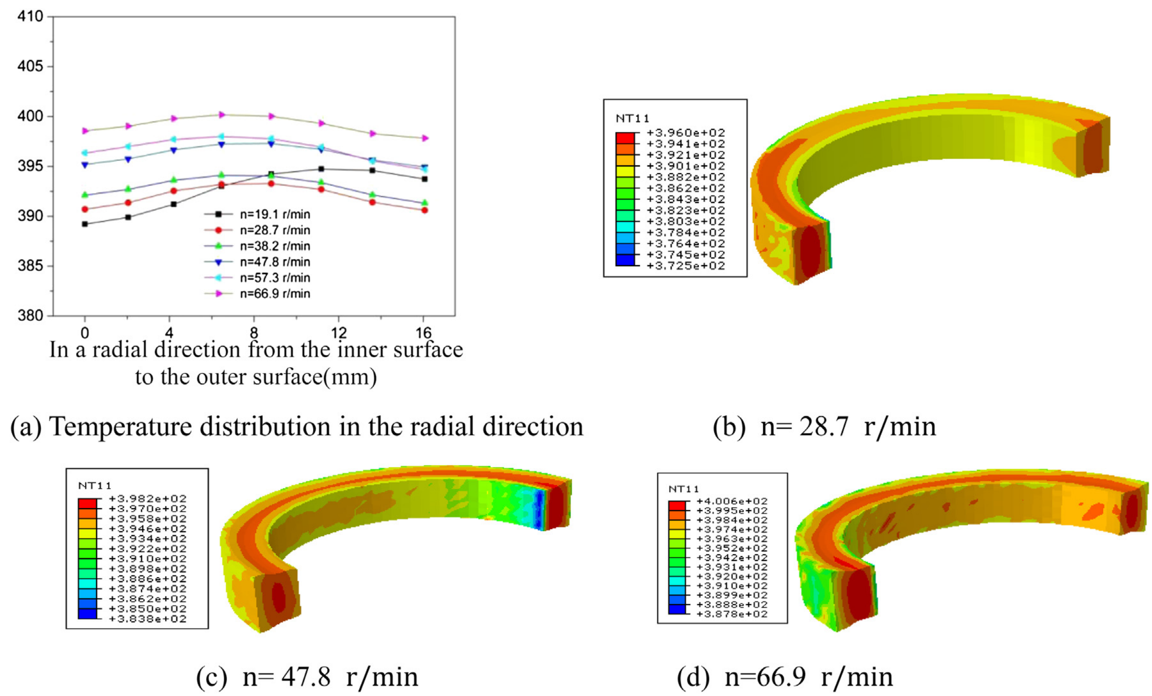


Fig. 4. Effect of drive roll feed on plastic strain.



(a) Temperature distribution in the radial direction (b) n= 28.7 r/min

(c) n= 47.8 r/min (d) n=66.9 r/min

Fig. 5. Effect of drive roll feed on temperature.

4.2. Effect of the driver roll rotational speed on fishtail coefficient

Fig. 6 illustrates the variation of fishtail coefficient with the *n* changing, From Fig. 6, it can be seen that the fishtail coefficient firstly decreases gradually, then increases with the increase of *n*. It indicates that the quality of end-plane become better then worse with the increase of *n*. This can be explained by the following aspects: on the one hand, when the *n* increases, the radial feed amount per revolution decreases, reducing the volume of metal in the deformation, the deformation is more uniform, ring shaped end face of increasingly good quality; on the other hand, as the Ring temperature rises, the mobility of the metal in the axial direction increases, while increasing the speed of ring, the ring surface was repeatedly rolling, the end surface of the molded ring quality begins to deteriorate.

4.3. Effect of n on rolling force parameters

4.3.1. Effect of n on rolling force

Fig. 7 shows the variation curves of the roll force with the *n* changing. From Fig. 7, it can be observed that the roll force decrease with the increase of *n*. That can be attributed to that: on the one hand, when the *n* increases, the radial feed amount per revolution decreases thus the less metal particulate in the plastic deformation resulting in a less power needed to produce plastic deformation; on the other hand, the heat generated by plastic deformation causes the increase of the temperature of the ring, with the result that the deformation resistance of the material decreases.

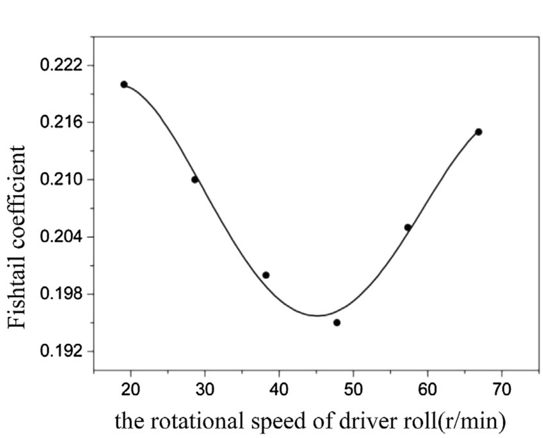


Fig. 6. Effect of *n* on fishtail coefficient.

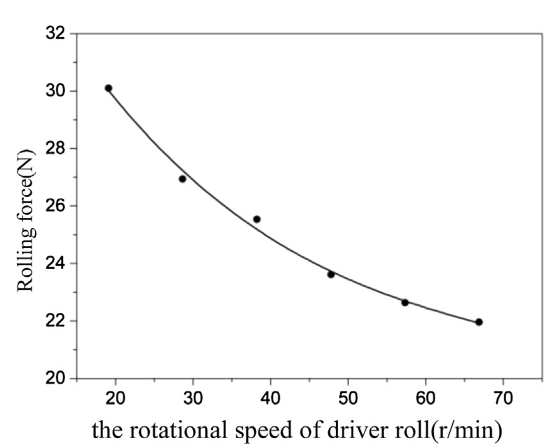


Fig. 7. Effect of *n* on rolling force.

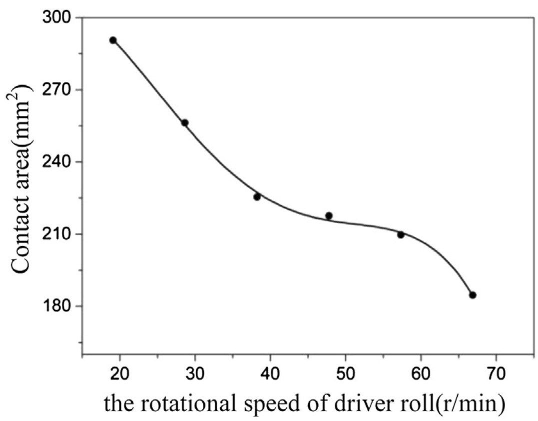


Fig. 8. Effects of *n* on contact area.

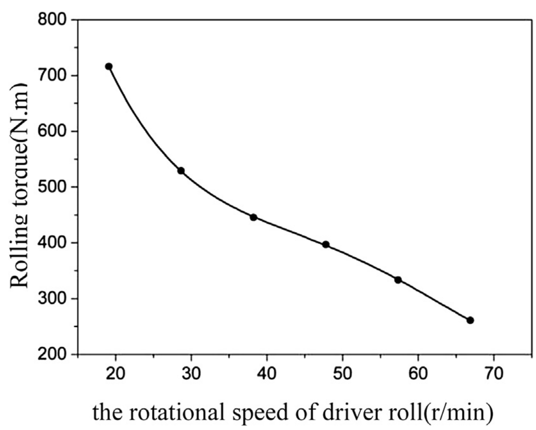


Fig. 9. Effect of *n* on rolling torque.

4.3.2. Effect of n on contact area

Fig. 8 shows the variation curves of the contact area with the *n* changing. From Fig. 8, it can be observed that the contact area decrease with the increase of *n*. That can be attributed to that, when the *n* increases, the radial feed amount per revolution decreases, thus the less metal particulate in the plastic deformation resulting in a less contact area.

4.3.3. Effect of n on rolling torque

Fig. 9 shows the variation curves of the rolling torque with the *n* changing. From Fig. 9, it can be observed that the rolling torque decrease with the increase of *n*. That can be attributed to that, when the *n* increases, rolling force gradually decreases, the roll contact area reduced, thereby reducing the rolling torque.

5. Conclusion

A 3D elastic–plastic and coupled thermo-mechanical FE model has been developed to discuss the effect of feed rate of drive roll on hot ring rolling of AZ31 magnesium alloy. The results are shown as follows:

(1) As *n* increases, the deformation of the rolled ring becomes less homogeneous, the temperature distribution of the rolled ring becomes more homogeneous, therefore, optimal rotational speed can be obtained.
(2) As *n* increases, Forming ring fishtail coefficient firstly decreases and then increases.
(3) As *n* increases, the rolling force, contact area and rolling moment gradually descend.

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