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Numerical Simulation and Process Research of 1500mm Twelve-Roll Copper-Steel-Copper Clad Rolling

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Abstract. The copper-steel-copper clad strip was commonly applied in many areas of life as a new type of clad material due to its superior mechanical qualities and significant economic benefits. The finite element model of copper-steel-copper clad rolling is created by ABAQUS. The finite element simulation of copper-steel-copper clad rolling is carried out by setting different reduction rates, rolling temperature and rolling speed. With increasing reduction rate, rolling speed and decreasing rolling temperature, the simulation results show a growing tendency toward the Mises stress of Q235. With the increase of rolling temperature, the Mises stress of H96 decreases gradually. The plastic strain of Q235 and H96 shows an upward trend with the increase of reduction rate. The convexity of the copper-steel-copper clad strip increases with the increase of reduction rate. Based on the orthogonal experimental method, taking the residual stress and belt convexity as the evaluation indexes, the optimal rolling process parameters of copper-steel-copper clad strip are studied through range analysis. The results show that the optimal rolling process parameters of copper-steel-copper clad strip are reduction rate of 40%, rolling temperature of 450°C and rolling speed of 100mm/s.

Keywords. Clad rolling, Orthogonal experiment, Process optimization, ABAQUS

1. Introduction

Copper-steel-copper clad strip not only has the high strength and weldability of steel but also has the advantages of excellent thermal conductivity of copper.[1] At present, the preparation methods of copper-steel-copper clad strip mainly include the explosive clad method and rolling clad method[2,3]. Through the finite element model of copper-steel-copper clad rolling, the effects of reduction rate, rolling temperature and rolling speed on copper-steel-copper clad rolling were studied.[4] At the same time, the optimal rolling process parameters of copper-steel-copper clad strip are obtained by orthogonal experiment.[5,6,7]

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2. Establishment of Finite Element Model for Copper-steel-copper Clad Rolling

2.1 Establishment of the Geometric Model

In the process of copper-steel-copper clad rolling, Q235 plain carbon steel is selected as steel[8] and H96 brass is selected as copper[9]. The geometric parameters of the steel strip are 200mm × 510mm × 8mm. The geometric parameter of the copper strip is 200mm × 510mm × 0.22mm. The geometric parameter of the work roll is Ø300mm × 1500mm. The finite element model of copper-steel-copper clad rolling is shown in Figure 1.

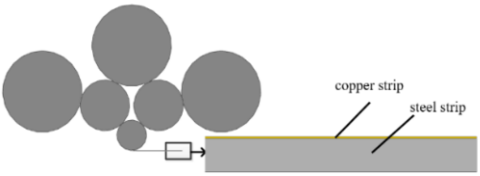


Fig.1 Finite element model of copper-steel-copper clad rolling

2.2 Setting of Material Properties

The stress-strain relationship of Q235[10] and H96[11] adopts J-C constitutive model. Its parameters are shown in Table 1. The material properties of plain carbon steel Q235 and brass H96 can be simulated by JMatPro[12].

Table 1 J-C constitutive model parameters of Q235 plain carbon steel and H96 brass

Material	A/MPa	B/MPa	C	n	m	Tm/K	Tr/K
Q235	293.8	230.2	0.0652	0.578	0.706	1795	293
H96	60.4	330.5	28400	0.311	1.152	1344	293

2.3 Mesh Settings

The mesh type is C3D8RT with a total of 76800 meshes. The model after meshing is shown in Figure 2.

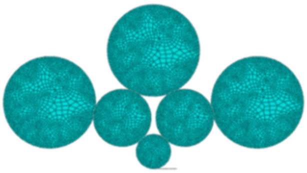


Fig.2 Model after meshing.

3. Results and Analysis of Copper-steel-copper Clad Rolling

According to the on-site rolling production requirements, the reduction rate ranges from 40% to 50%, the rolling speed ranges from 50mm/s to 100mm/s and the rolling temperature ranges from 250°C to 500°C. The flow of copper and iron metal in the rolling process is shown in Figure 3.

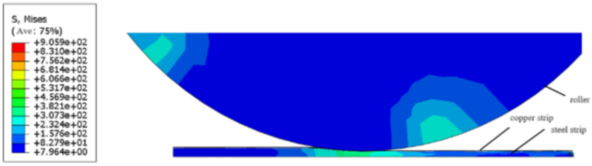
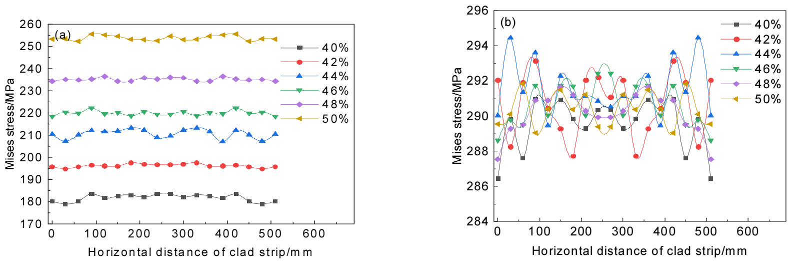


Fig.3 Schematic diagram of metal flow in the deformation zone of the rolling process

3.1 Effect of Reduction Rate on Copper-steel-copper Clad Strip

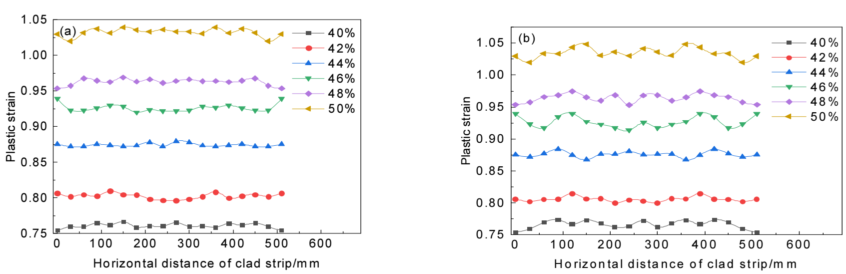
The rolling process is set as the rolling speed of 100mm/s and the rolling temperature of 250℃. The reduction rate is divided into six levels: 40%, 42%, 44%, 46%, 48% and 50%. As can be seen from Figure 4, when the reduction rate increases from 40% to 50%, the Mises stress of Q235 shows an increasing trend. The Mises stress of the H96 fluctuates up and down around 290Mpa. This may be because the copper strip is very thin compared with the steel strip and its deformation resistance is large.



(a)Q235 (b)H96

Fig.4 Mises stress distribution curves of different transverse joints of copper-steel-copper clad strip with different reduction rates

As can be seen from Figure 5, when the reduction rate increases from 40% to 50%, the plastic strain of Q235 and H96 is increasing continuously. The reason is that within the current reduction rate range, the Q235 has reached the strengthening stage and work hardening has occurred in the material. The H96 reached the yield limit and the material entered the yield.



(a)Q235 (b)H96

Fig.5 Plastic strain distribution curves of different transverse joints of copper-steel-copper clad strip with different reduction rates

As can be seen from Figure 6, there is a positive correlation between belt convexity and reduction rate. The reason is that the main factor affecting the belt crown is the deformation of the roll.

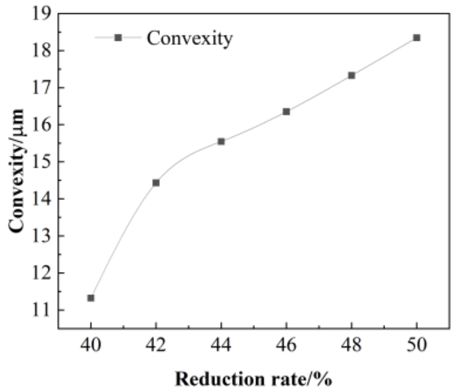
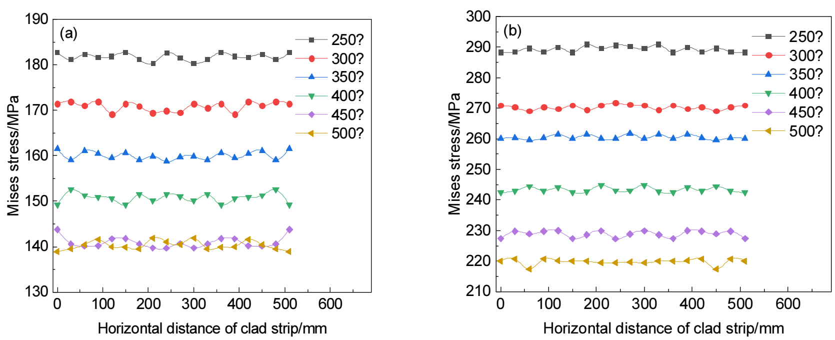


Fig.6 Belt convexity curve of copper-steel-copper clad strip with different reduction rate

3.2 Effect of rolling temperature on copper-steel-copper clad strip

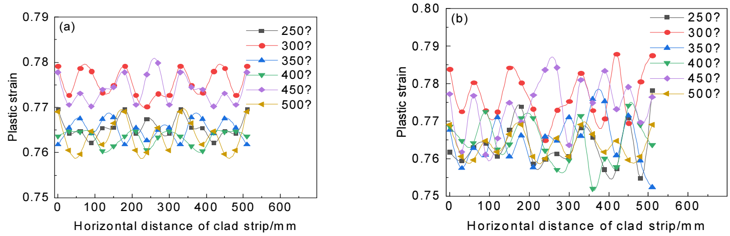
The rolling process is set as the reduction rate of 40% and the rolling speed of 100mm/s. The rolling temperature is divided into six temperatures: 250℃, 300℃, 350℃, 400℃, 450℃ and 500℃.

As can be seen from Figure 7, when the rolling temperature increases from 250℃ to 500℃, the Mises stress of Q235 and H96 gradually decreases. This is because when the temperature increases, the metal deformation resistance decreases. It can be seen from Figure 8 that when the rolling temperature increases, the plastic strain of Q235 and H96 fluctuates between 0.75 and 0.80. As can be seen from Figure 9, with the increase of rolling temperature, the belt crown first increases and then decreases. The increase of rolling temperature will improve the plastic deformation ability of the material and reduce the rolling force.



(a)Q235 (b)H96

Fig.7 Mises stress distribution curves of different transverse joints of copper-steel-copper clad strip at different rolling temperatures



(a)Q235 (b)H96

Fig.8 Plastic strain distribution curves of different transverse joints of copper-steel-copper clad strip at different rolling temperatures

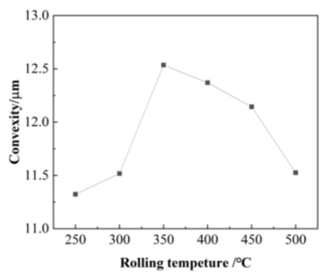
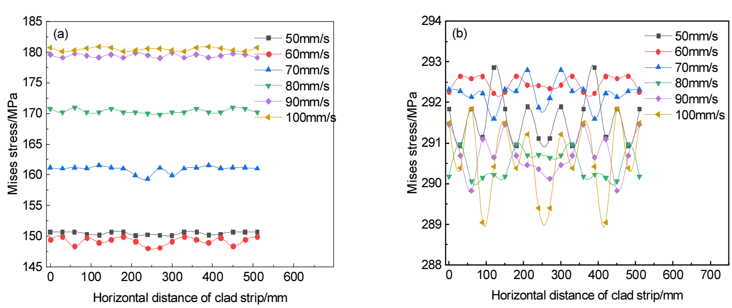


Fig.9 Belt convexity curve of copper-steel-copper clad strip at different rolling temperatures

3.3 *Effect of Rolling Speed on Copper-steel-copper Clad Strip*

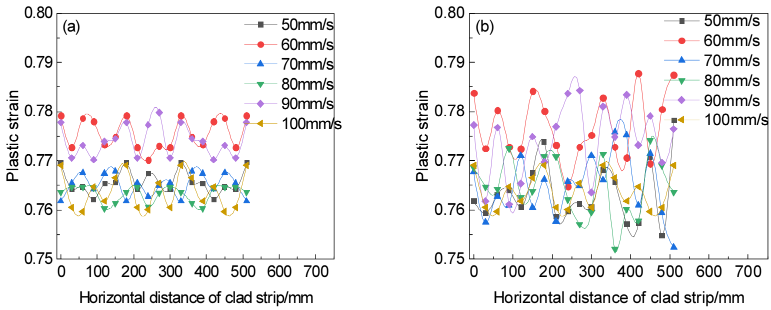
The rolling process is set as 40% reduction rate and 250°C rolling temperature. The rolling speed is divided into six speeds: 50mm/s, 60mm/s, 70mm/s, 80mm/s, 90mm/s and 100mm/s.

As can be seen from Figure 10, when the rolling speed increases from 50mm/s to 100mm/s, the Mises stress of Q235 increases by nearly 30MPa . The Mises stress of H96 decreases slightly. As can be seen from Figure 11, the plastic strain of Q235 and H96 fluctuates between 0.76 and 0.78 when the rolling speed increases. As can be seen from Figure 12, with the continuous increase of rolling speed, the belt crown shows a downward trend as a whole. This is because the rolling speed affects the heat transfer coefficient and contact time in the rolling contact area.



(a)Q235 (b)H96

Fig.10 Mises stress distribution curves of different transverse joints of copper-steel-copper clad strip at different rolling speeds



(a)Q235 (b)H96

Fig.11 Plastic strain distribution curves of different transverse joints of copper-steel-copper clad strip at different rolling speeds

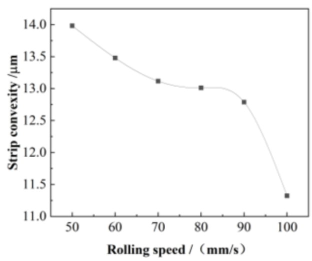


Fig.12 Belt convexity curve of copper-steel-copper clad strip at different rolling speeds

4. Study on Optimal Rolling Process Parameters of Copper-steel-copper Clad strip Based on Orthogonal Experiment

4.1 Orthogonal Experimental Scheme Design

Orthogonal experimental is a scientific and efficient experimental method to deal with and analyze multi factor and multi-level conditions[13]. The reduction rate, rolling temperature and rolling speed are taken as the research factors. Each factor is divided into five levels as shown in Table 2. The range analysis method[14] is used to evaluate the rolling process parameters. The evaluation indexes are residual stress and belt convexity.

Table 2 Three factors and five levels of orthogonal experiment

Factor / Level	A Reduction rates (%)	B Rolling temperatures (°C)	C Rolling speeds (mm/s)
1	40	250	50
2	44	350	70
3	46	400	80
4	48	450	90
5	50	500	100

4.2 Analysis of orthogonal experimental results

According to the factor levels in Table 2, 25 groups of working conditions are obtained through orthogonal experimental design. The residual stress and belt convexity obtained by finite element simulation under different experimental conditions are shown in Table 3.

Table 3 Orthogonal test scheme and simulation result

Experiment serial number	Experimental scheme	Residual stress/ (MPa)	Belt convexity/ (μm)	Experiment serial number	Experimental scheme	Residual stress/ (MPa)	Belt convexity/ (μm)
1	$A_1B_1C_1$	155.15	13.56	14	$A_3B_4C_1$	145.52	20.99
2	$A_1B_2C_2$	179.13	11.59	15	$A_3B_5C_2$	154.86	26.70
3	$A_1B_3C_3$	152.53	10.22	16	$A_4B_1C_4$	237.81	14.95
4	$A_1B_4C_4$	165.84	8.38	17	$A_4B_2C_5$	210.67	12.32
5	$A_1B_5C_5$	150.54	14.71	18	$A_4B_3C_1$	166.32	25.28
6	$A_2B_1C_2$	196.60	11.93	19	$A_4B_4C_2$	166.35	24.69
7	$A_2B_2C_3$	183.31	11.44	20	$A_4B_5C_3$	175.28	32.53
8	$A_2B_3C_4$	181.77	12.90	21	$A_5B_1C_5$	253.87	14.24
9	$A_2B_4C_5$	171.02	11.21	22	$A_5B_2C_1$	190.67	20.43
10	$A_2B_5C_1$	138.73	25.52	23	$A_5B_3C_2$	191.97	23.87
11	$A_3B_1C_3$	200.02	13.93	24	$A_5B_4C_3$	190.11	24.15
12	$A_3B_2C_4$	185.51	12.45	25	$A_5B_5C_4$	199.25	29.66
13	$A_3B_3C_5$	176.09	11.15				

4.2.1 Residual Stress Range Analysis

The range analysis method is used to analyze the residual stress. It can be seen from Table 4 that the average residual stress of copper-steel-copper clad belt increases from 160.64MPa to 205.18MPa with an increase of 27.7% when the reduction rate increases gradually. Therefore, the optimal reduction rate is 40%. With the increase in rolling temperature, the average residual stress decreases from 208.69MPa to 163.73MPa. This is because the higher the temperature, the better the plastic formability of the strip. Therefore, the optimal rolling temperature is 500°C. With the increase in rolling speed, the average residual stress increases from 159.28MPa to 192.44MPa. This is because the rolling speed will lead to an increase in strain rate and deformation resistance. Therefore, the optimal rolling speed is 50mm/s.

Table 4 Residual stress range analysis

Level	Factor			S
	A	B	C	
1	160.64	208.69	159.28	
2	174.28	189.86	177.78	$\bar{S}$
3	172.40	173.74	180.25	
4	191.28	167.77	194.04	180.76
5	205.18	163.73	192.44	
Range	44.54	44.96	34.76	
Primary and secondary order		B、A、C		
optimal combination		$A_1B_5C_1$		

4.2.2 Belt Convexity Range Analysis

The range analysis method is used to analyze the belt convexity of the copper-steel-copper clad strip. From Table 5, it can be seen that as the reduction rate increases, the rolling temperature increases, and the rolling speed decreases, the strip crown shows an increasing trend. So the reduction rate is 40%. The rolling temperature is 350℃. The rolling speed is 100mm/s.

Table 5 Plate thickness convexity range analysis

Level	factor			d
	A	B	C	
1	11.69	13.72	21.16	
2	14.60	13.65	19.76	
3	17.04	16.68	18.45	$\bar{d}$ 17.55
4	21.95	17.88	15.67	
5	22.47	25.82	12.72	
Range	10.78	12.17	8.44	
Primary and secondary order		B、A、C		
optimal combination		$A_1B_2C_5$		

4.3 Analysis of Orthogonal Experimental Results

By comparing the optimal process level combination corresponding to the two indexes, it is found that the level corresponding to reduction rate is consistent, while the level corresponding to rolling temperature and rolling speed are inconsistent. Therefore, it is necessary to comprehensively analyze the effects of rolling temperature and rolling speed on residual stress and belt convexity to obtain the optimal rolling process parameters of copper-steel-copper clad strip.

4.3.1 Determination of Rolling Temperature

As can be seen from Figure. 13, the residual stress gradually decreases with the increase of rolling temperature and its variation range decreases. The belt convexity increases with the increase of rolling temperature and its variation range increases gradually. When the rolling temperature is 400℃ to 450℃, the residual stress fluctuates between 165Mpa and 175Mpa with a varied range of about 9%. Belt convexity is 16.7μm to 17.9μm with a varied range of about 7%. Therefore, it is better to select the rolling temperature of 450℃ considering and comparing the residual stress and belt convexity under other temperature conditions.

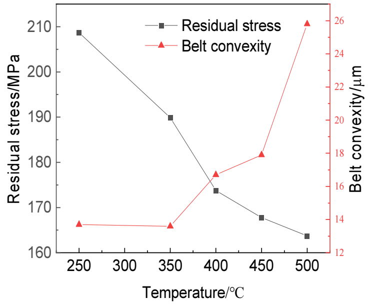


Fig.13 Variation curves of residual stress and belt convexity with rolling temperature

4.3.2 Determination of Rolling Speed

It can be seen from Figure. 14 that the residual stress increases gradually and its variation range decreases gradually with the increase in rolling speed. The belt convexity decreases and its variation range increases gradually with the increase of rolling speed. When the rolling speed is 90mm/s to 100mm/s, the fluctuation of residual stress is small. When the rolling speed is 100mm/s, the value of belt convexity is the smallest. Because the rolling speed not only affects the attribute parameters of the strip but also affects the rolling efficiency. The rolling speed should be improved as much as possible on the premise of meeting the quality requirements. Therefore, it is more appropriate to select the rolling speed of 100mm/s.

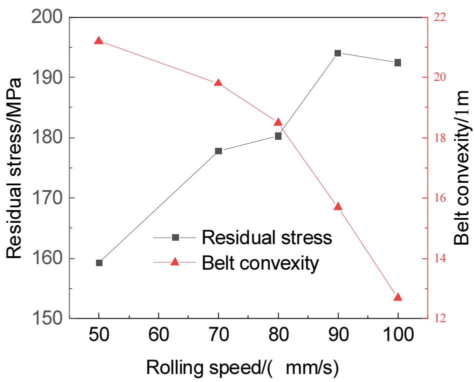


Fig.14 Curves of residual stress and plate thickness convexity as a function of rolling speed at each level

Based on the above analysis, the optimal rolling process parameters of copper-steel-copper clad strip are reduction rate of 40%, rolling temperature of 450℃ and rolling speed of 100mm/s.

5. Conclusion

(1) The finite element model of copper steel copper composite rolling is established by ABAQUS.

(2) When the reduction rate increases, the Mises stress of Q235 increases. The Mises stress of the H96 fluctuates in a small range. The plastic strain of Q235 and H96 is increasing. The belt convexity shows an increasing trend.

When the rolling temperature increases, the Mises stress of Q235 and H96 decreases gradually. The plastic strain fluctuates in a small range. The belt convexity increases first and then decreases.

When the rolling speed increases, the Mises stress of Q235 increases continuously. The Mises stress of the H96 decreases slightly and fluctuates in a small range. The plastic strain of Q235 and H96 fluctuates in a small range. The belt convexity shows a downward trend as a whole.

(3) For the warm rolling production of copper steel copper composite strip, on the premise that the products meet the quality requirements and consider the problems of production efficiency and energy consumption, the optimal rolling process parameters are reduction rate of 40%, rolling temperature of 450℃ and rolling speed of 100mm/s.

Acknowledgement

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