Numerical Simulation Analysis of Surfacing Temperature Field of Pulling-straightening Roller

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Abstract. In this paper, the ANSYS software thermal analysis is used to simulate the 0Cr13Ni4MoN surfacing process of the pulling-straightening roller. The Gaussian model was selected as the heat source model, and the direct solution method was used to calculate the temperature field of the surfacing process. The effects of preheating temperatures of 250°C, 300°C and 350°C on the temperature field of the pulling-straightening roller were discussed. The results show that the preheating temperature range of 250~350°C gives a uniform temperature field.

1. Introduction
The pulling-straightening rollers are the main components of the continuous casting and rolling equipment, the role of the pulling-straightening roller is to correct, guide and drive the plastic deformation of the casting blank[1]. The general method used for the repair of the pulling-straightening roller is the overlay welding repair method, that is, the alloy material is deposited on the base material substrate. 0Cr13Ni4MoN has good plasticity, wear resistance, heat resistance, corrosion resistance, etc[2]. It is suitable as a surface coating material for pulling-straightening roller, which can improve the service life of the roller body and the quality of the steel slab. The finite element analysis software ANSYS gradually includes various engineering field solving capabilities in the development process. After having stable and reliable structural strength analysis and thermal analysis functions, it has been developed and expanded to be used more widely. In this paper, the software ANSYS version 14.0 was used to simulate the surfacing temperature field.

2. The Simulation Calculation of Temperature Field
2.1. Material Properties of 0Cr13Ni4MoN
0Cr13Ni4Mo is a nickel-containing, molybdenum ultra-low carbon martensitic stainless steel. It adds nickel and molybdenum to the chromium martensitic stainless steel and reduces the carbon content[3]. Material properties below 500°C including 500°C can be found by data, while properties above 500°C need to be calculated by software. In the numerical simulation of the temperature field of the pulling-straightening roller surfacing process, it is necessary to add some material properties such as density DENS (Kg/m³), specific heat capacity C (J/Kg·K), heat transfer coefficient KXX [W/(m·K)] and so on. These material parameters are all required for thermal analysis. The thermal conductivity of
0Cr13Ni4Mo in the range from room temperature 20°C to melting temperature 1500°C is 34 W/(m·K), and the specific heat capacity is 683 J/Kg·K.

2.2. Establishment of Finite Element Model
Generally, the length of the pulling-straightening roller is long, so a section of the roller is used as a model for simulation. The three-dimensional model for simulation uses a hollow roller, and the hollow roller is cooled by internal circulating water.

Solid model size: the size of the pulling-straightening roller is 200 mm×100 mm×20 mm. The digital model is built using the CAD software CATIA, and then the entity model is imported through the ANSYS and CATIA software data interface. The solid model is shown in Figure1.

2.3. Meshing
The pulling-straightening roller is a hollow cylinder structure, which can be meshed by a mapping meshing method, and the main body of the pulling-straightening roller and the welding layer are divided into regular hexahedrons. The mesh size of the main body of the pulling-straightening roller is about 3 times larger than the mesh size of the overlay layer. The mesh of the main body and the mesh of the overlay layer are connected by a tetrahedron, which can improve the speed of the computer operation and reduce the calculation time, and also guarantee the degree of compliance with the actual calculation. Since the pulling-straightening roller is an axisymmetric structure, a 1/4 model is used for the simulation calculation. The finite element model meshing is shown in figure 2.

2.4. Selection of Heat Source
It has been found that Gaussian distribution function can effectively improve the calculation accuracy when penetration ability of manual arc welding and tungsten argon arc welding is small. Eagar and Tsai’s gaussian mathematical model was used to calculate the heat flux distribution on the welding spot [4]. Its function was as follows:

$$q(r) = \frac{3\eta U I}{\pi R^3} \exp \left( -\frac{3r^2}{R^2} \right)$$

Where: R— the effective heating radius of the arc, the unit is mm; r— the distance from any spot on the weldment to the center of arc heating spot, the unit is mm; \(\eta\) — welding thermal efficiency; U— welding voltage, the unit is V; I— welding current, the unit is A.

Arc welding is a continuous dynamic process. Since the Gaussian heat source is a transient command, if the heat source is to be surfacing in a certain direction during the surfacing process, it needs to be programmed in the APDL language. APDL is the ANSYS parametric design language, it is an interpretive language that can be used to build models based on parameters [5]. In transient thermal analysis, after the initial temperature is specified, the temperature will change with time due to the thermal load [6].

This topic to be discussed under different preheating temperature for the pulling-straightening roller overlaying welding temperature field, the influence of the temperature 250°C, 300°C and 350°C respectively. The initial conditions for: the pulling-straightening roller matrix correction temperature is...
250°C, 300°C, 350°C. The initial temperature of the surfacing layer is 1659°C, and the convective boundary conditions: convective heat transfer coefficient is 45.42 W/(m²·°C), and air temperature is 20°C.

2.5. Analysis of Temperature Field Results

As shown in Figure 3~5, when the welding current I=340A, the voltage U=32V, the welding speed v=15cm/min, the temperature field simulation results at different times during the welding process are as follows.

In the initial stage of surfacing welding, the heating rate of the matrix is slow, so it is seen that the base metal temperature is around 1400°C in the initial stage, as the heat source is loaded and moved in the circumferential direction, the surface of the roller body in the forward direction of the heat source is affected by the preheating of the welding heat source, and the temperature in the vicinity of the heat source rises rapidly, and the area of the high temperature region is also expanded. In Figure 4, in the welding process, based on the gradual preheating phenomenon of welding heat source on roll body, the temperature at the next moment of the welding heat source will be higher than that at the previous moment, the welding temperature can be well controlled during the surfacing process without major fluctuations. The maximum temperature of the welding temperature field is not stable, and the temperature is gradually increasing as the heat source moves. According to the observation in Figure 5, when the temperature of the temperature field changes greatly, the expansion of the molten pool is very small, and the calorific value of the surface swept by the heat source changes little compared with that before, but the overall temperature of the roller body increases continuously after welding.

![Figure 3](image1.png)

**Figure 3.** Simulation results of the initial stage of surfacing
(a) Temperature field distribution at 3.9s  (b) Temperature field distribution at 7.8s

![Figure 4](image2.png)

**Figure 4.** Simulation results of the intermediate stage of the overlay welding
(a) Temperature field distribution at 39.3s  (b) Temperature field distribution at 161.0s
Figure 5. Simulation results at the end of the surfacing process
(a) Temperature field distribution at 247.4s (b) Temperature field distribution at 251.3s

Normally, for large roller bodies, preheat treatment is required before welding, so the influence of
temperature on the temperature field is simulated by different preheating conditions. The four
preheating temperature parameters selected below are 20°C (no preheating) 250°C, 300°C and 400°C.

Figure 6 shows the effect of different preheating temperatures on the welding temperature field.
(a) No preheating temperature (b) 250°C (c) 300°C (d) 350°C

Figure 6 shows the effect of different preheating temperatures on the welding temperature field. In
Figure 6(b), the preheating temperature before welding is 250°C, and the maximum temperature of the
temperature field is about 2060°C at around 40s. In Figure 6(c), (d), the preheating temperatures
respectively are 300°C and 350°C, the peak temperature of the temperature field respectively are 2115
°C and 2159°C, it can be inferred that the preheating temperature value directly affects the temperature
field after cooling, and they are in a positive proportional relationship.

Figure 7 shows the temperature field-time plot of node 1755, which contains three different preheat
temperatures. When the heat source does not move to the node, the temperature of the node will always
maintain the temperature of the preheating field. After the heat source moves to the node, the
temperature of the node will rise rapidly, the duration of high temperature peak is short, and then it will drop rapidly, and finally the node reaches the equilibrium temperature. In the figure, with the increase of preheating temperature value, the node temperature value increases correspondingly, and the final equilibrium stable temperature value is higher. The peak width of calorific value did not change with the change of preheating temperature value, but the peak value changed greatly with the change of preheating value. The three sets of graphs show that the curve heating rate and the cooling rate are basically equal, and the change is small.

![Figure 7. Effect of preheating temperature on temperature field](image)

3. Conclusion
1. When the welding current is I=340A and the welding speed is v=15cm/min, the center temperature of the molten pool is about 1600°C in the initial stage of surfacing. Under the condition of heat source continues to move forward, the internal temperature of the molten pool slowly rise from 1600°C to 1900°C, indicating that each weld to be affected by excessive temperature zone in the former period, makes the molten pool temperature increased slowly.
2. If the surfacing is done without preheating, temperature of overall roll is low and The temperature of roller body is quite different from that of surfacing layer so that the temperature is difficult to rise rapidly. At 250°C, 300°C and 350°C preheat temperature conditions, the difference of heat affected zone temperature decreases. Even though it is in the early stages, the roll body temperature field distribution is more homogeneous.

Acknowledgements
This work is financially supported by the Natural Science Foundation of China (No.51604034) and the Science and Technology Development Plan Project Specification of Jilin province (No.20190302003GX).

References
[1] Zeng Zhiling, Ren Lijun. Thermal-structure coupling analysis of pulling-straightening roller using ANSYS software[J]. Heavy Machinery.
[2] Chen Hua, Wang Liyan, Liu Xiaochun. Study on Microstructure and Properties of Welding of Pulling-straightening Roller[J]. Thermal Process Technology.
[3] Zhang Wenqian. Welding heat transfer [M]. Beijing: Mechanical Industry Press.
[4] Liu Zhe et al. Three-dimensional Dynamic FEM Simulation of Temperature Distribution with Thermo-metallurgical Interaction During Welding [J]. Mechanical science and technology.
[5] Zheng Yongyang, Gao Peng, Ansys APDL-use of Finite Element Simulation Structure[J]. Architecture and structural design.
[6] U shio, M Proc. Metallo-thermo-mechanics application to phase transformation incorporated processes [J].