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A Study on temperature field and spheroidizing annealing process in Bell-type annealing furnace

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Abstract. The convection heat transfer coefficient and equivalent radial thermal conductivity are two important parameters of the heat transfer process in bell-type annealing furnace. This paper establishes finite element model and calculates temperature field. The model treats the boundary condition based on actual annealing process curve, so it has a certain accuracy. According to the simulation results, spheroidizing annealing process of high carbon saw steel has been made. Through this process, it can obtain good spheroidized annealing tissues, and mechanic property parameters such as yield strength, tensile strength and hardness have been improved significantly.

1 Introduction

The bell-type annealing furnace is used in Shougang Qiangang Hot Rolling Plant, in order to change the material properties, we can control the temperature and time of heating, holding and cooling of the hot-rolled coil. For the two most important parameters of the heat transfer process in bell-type annealing furnace: convection heat transfer coefficient and equivalent radial thermal conductivity, some scholars have carried out some research[1, 2]. Based on previous studies, this paper establishes finite element model and calculates temperature field distribution in the annealing process, and develops a set of spheroidizing annealing process for high carbon saw steel 8CrV.

2 Mathematical Model of Heat Transfer

2.1 Equation of Temperature Field and Boundary Condition

Taking into account the axial symmetry of the coils and the bell-type annealing furnace, the simplification is performed according to the heating characteristics during the annealing process[3]:

1) There is no heat source inside the coil.

2) The heat transfer between coil boundary and external is in accord with the third kind of boundary condition.

3) Ignore the circumferential heat conduction, only consider heat conduction along the radial and axial.

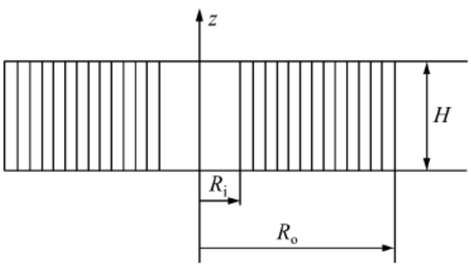

Fig. 1 Physical model of heat transfer of coils

According to the coil heat analysis and physical model during the annealing process, the model cylinder coordinates are shown in Fig 1. The differential equation of two-dimensional axisymmetric and Non-steady state heat conduction is established[4]:

$$\rho c_P \frac{\partial t}{\partial \tau} = \frac{1}{r}\frac{\partial}{\partial r}\left(r\lambda_r \frac{\partial t}{\partial r}\right) + \frac{\partial}{\partial z}\left(\lambda_z \frac{\partial t}{\partial z}\right) \quad (1)$$

The solving conditions of differential equation of heat conduction mainly include: geometric conditions, initial conditions, and boundary conditions[5].

The initial conditions: $\tau = 0$， $t(r,\tau) = t_0$ $(R_i < r < R_0; 0 < z < H)$

The outer surface: $-\lambda_r \frac{\partial t}{\partial r} = h_{ro}(t - t_f)$

The inner surface: $-\lambda_r \frac{\partial t}{\partial r} = h_{ri}(t - t_f)$

Axial convective heat transfer: $-\lambda_z \frac{\partial t}{\partial z} = h_z(t - t_f)$

where r is the radial radius of coil; z the axial coordinates; ρ the density of steel; λ_r the radial equivalent thermal conductivity; λ_z the axial thermal conductivity; τ time; t_0 the initial temperature; t_f the average temperature of the protective gas in the furnace; R_i and R_0 the inside diameter and outside diameter of coils; h_{ro} , h_{ri} and h_z the convective heat transfer coefficient of inner, outer surface and end face of coil.

The convection heat transfer coefficient and equivalent radial thermal conductivity are two important parameters of the heat transfer process in bell-type annealing furnace, and also directly determine the calculation accuracy of transient heat transfer finite element model. Therefore, how to solve these two parameters that is the key factor to solve the temperature field distribution during annealing process.

2.2 Convection heat transfer coefficient

The convection heat transfer is the main heat transfer method, and the heat transfer coefficient of the gas and surface of coil can be calculated by the following formula[6]:

$$h = 0.023\xi \frac{V_g^{0.8}}{D_g^{0.2}} \lambda_g \left(\frac{u_g}{\rho_g}\right)^{-0.8} \left[1 + \left(\frac{D_g}{L_g}\right)^{0.7}\right] \quad (2)$$

where V_g is the gas flow rate; λ_g the thermal conductivity of gas; u_g the gas dynamic viscosity; ρ_g the gas density; D_g the gas flow diameter; L_g the length of the gas flow path; ξ the heat transfer enhancement coefficient due to swirl.

From formula(2), we can see that the convective heat transfer coefficient is closely related to the flow rate and thermal properties of the shielding gas.

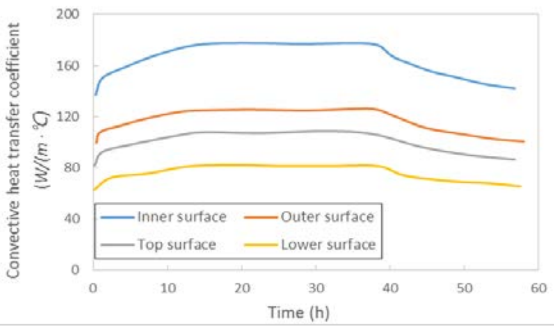

Fig. 2 The heat transfer coefficient of coil’s four surfaces

Figure 2 shows the change law of convection heat transfer coefficient of coil four surfaces with the entire annealing process.

2.3 Equivalent radial thermal conductivity

Equivalent radial thermal conductivity is calculated using the following formula [7]:

$$\lambda_r = \frac{s+b}{\dfrac{s}{\lambda_s} + \left\{ \dfrac{4(1-\varphi)\varepsilon\sigma T_m^3}{2-\varepsilon} + (1-\varphi)\dfrac{\lambda_F}{b} + \dfrac{1.13\lambda_s \tan\theta}{\sigma_p}\varphi^{0.94} \right\}^{-1}} \quad (3)$$

where s is the thickness; b the gap between the strip layer and the layer; λ_s and λ_F the thermal Conductivity of strip and shielding gas; σ the Boltzmann constant; σ_p the roughness of strip surface; P the coiling tension.

3 Finite Element simulation of temperature field

In the simulation calculations, we can adjust the equivalent thermal conductivity coefficient to correct simulation errors by according to the measured data. This finite element model selects the SOLID70 three-dimensional hexahedron eight-node unit, and the meshing density was 0.05. The boundary conditions of the temperature field is applied by according the actual annealing process curve.

Along the radial direction of the coil, four unit nodes are selected equally. The four nodes' temperature curve over time during annealing process are shown in Figure 3.

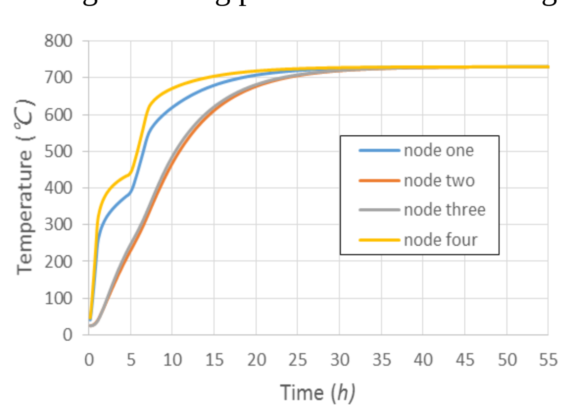

Fig. 3 Temperature curves of four nodes

4 Application

According to the temperature field distribution results of finite element model, the spheroidizing annealing parameters of high carbon saw steel 8CrV are developed. Compared with the hot rolled coil, the mechanical properties of the high carbon saw steel 8CrV after spheroidizing annealing are obviously improved. The average values of the mechanical properties are shown in Table 1. The microstructure after Annealing are shown in Figure 4.

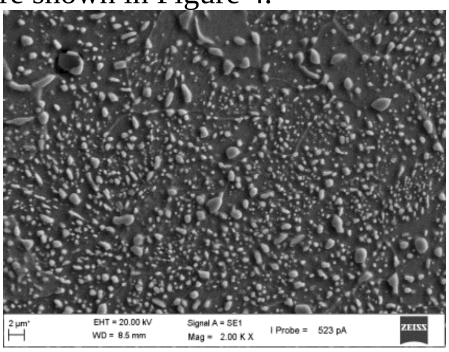

Fig. 4 Microstructure after spheroidized Annealing

The yield strength decreased about 200~300MPa, tensile strength decreased about 400~500MPa, Brinell hardness HBW10/3000 decreased by about 100, the effect of spheroidizing annealing is very significant.

Table 1 Comparison of mechanical properties before and after spheroidizing annealing

Grade	State	$Rp_{0.2}$ (*MPa*)	R_m (*MPa*)	A (*%*)	*HBW10/3000*
8CrV	hot rolled	650	1120	10	320
	annealing	406	719	18	167

3 Conclusion

Finite Element simulation models of annealing process are established to analyze the temperature field distribution. According to the simulation results, the more suitable spheroidizing annealing parameters of high carbon saw steel 8CrV are developed. Actual production data indicate that the mechanical properties are obviously improved after annealing, compared with the hot rolled coil.

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