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STUDY ON THE BEST METHOD OF CONTROLLED COOLING FOR ROLLED ANGLE STEEL

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In this paper, the large-scale finite element analysis software ANSYS is used to establish the three-dimensional finite element model of angle steel and analyze the temperature field during the cooling process. Taking the spray density and spray speed as the design variables, the temperature gradient as the state variables, and the maximum temperature difference as the objective function, the optimization design of angle steel controlled cooling method is carried out. The results show that the maximum temperature difference of angle steel is reduced and the temperature distribution is more uniform after optimization, which has a very important guiding significance for the reasonable customization of angle steel controlled cooling process.

Keywords: steel, controlled cooling, temperature field, heat transfer, finite element model

INTRODUCTION

The so-called controlled cooling is to make use of the corresponding cooling conditions of steel after hot rolling. Through the control of the corresponding conditions, the reasonable control of the transformation conditions, the steel properties and microstructure after transformation, the state of austenite and the actual precipitation of carbide can be realized [1]. At present, there are two prominent problems in various iron and steel enterprises, namely, the serious shortage of cooling bed capacity and the low comprehensive mechanical properties of steel [2].

Controlled cooling technology is to make good preparation for steel phase transformation by reasonably controlling the cooling process parameters of rolled steel, and improve the comprehensive mechanical properties and service performance of steel by controlling the cooling rate of phase transformation process. As a new technology in the field of modern steel rolling technology, controlled cooling technology not only fully exploits the potential of steel, but also simplifies the production process and improves the production efficiency [3].

ESTABLISH FINITE ELEMENT MODEL

ANSYS finite element analysis software is used to establish the finite element model of angle steel of 100 mm × 100 mm × 12 mm. It used solid90 unit in ANSYS software when modeling. Solid90 element is a 20 node hexahedral element, which can be used to model static or transient heat conduction problems [4]. This element has higher accuracy, but it takes more time to solve the problem. Each node has only one degree of freedom, which is temperature. The element is also suitable for modeling curved boundary problems. The output of the unit includes node temperature and other information, such as average surface temperature, temperature change rate component, temperature vector at the center of mass and heat flux component [5].

Figure 1 shows the grid division of the three-dimensional model of angle steel. Considering the limitation of computer resources, it takes the length of angle steel as 0,5m. From Figure 1, it can see that there is little difference between the length and width of the grid, which is similar to the square grid, which can ensure the accuracy. The finite element model contains 24 000 solid90 elements and 107 913 nodes, which can meet the requirements of calculation speed and accuracy.

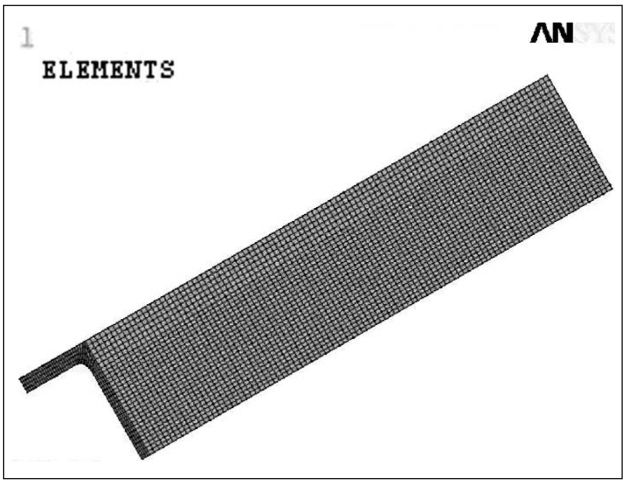

Figure 1 The finite element model of angle steel

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ANALYSIS OF TEMPERATURE FIELD OF ANGLE STEEL CONTROLLED COOLING

During the controlled cooling of angle steel, the cooling medium of the fluid contacts with the surface of angle steel and uses the difference of temperature between them to produce heat transfer. This process is called convective heat transfer. No matter what kind of cooling method or cooling medium is used, the convective heat transfer coefficient is an important index to indicate the cooling capacity of angle steel. The calculation of cooling capacity of various cooling methods of angle steel is also directly related to the heat transfer coefficient. Newton's cooling formula has been used to calculate the heat carried away by the cooling medium in convective heat transfer.

$$Q = \alpha A \Delta t$$

α – heat transfer coefficient / $W \cdot m^{-2} \cdot °C^{-1}$;
A – Heat transfer area / m^2;
Δt – Temperature difference between fluid and angle steel surface.

The heat transfer coefficient formula of air cooling stage is as follows:

$$h = 2{,}25(T_w - T_c)^{0{,}25} + 4{,}6 \text{ x } 10^{-8} (T_w^2 + T_c^2)(T_w + T_C)$$

T_w – Surface temperature of angle steel
T_c – environmental temperature

The controlled cooling method of angle steel is spray cooling, and the formula of spray cooling capacity is calculated:

$$log\alpha = 3{,}33 - 0{,}857\ log\Theta_r + 0{,}662\ logW + 0{,}308\ logV$$

$$450°C \le \Theta_r \le 600°C$$

$$log\alpha = 1{,}40 - 0{,}136\ log\Theta_r + 0{,}629\ logW + 0{,}273\ logV$$

$$\Theta_r \ge 600°C$$

α – heat transfer coefficient/ $W \cdot m^{-2} \cdot °C^{-1}$
Θ_r – Surface temperature of angle steel/°C
W – Current density/$L \cdot m^{-2} \cdot min^{-1}$
V – Jet velocity of water/ $m \cdot s^{-1}$

This paper adopts the method of simultaneous cooling, that is, after the angle steel enters the water cooling zone as a whole, spray and cool the angle steel, so as to ensure the simultaneity of the cooling and make the parts cool evenly. By simulating the temperature field of the three-dimensional model of the angle steel, we can get the temperature distribution along the length direction of the angle steel after controlled cooling.

Figure 2 is the result of temperature gradient before optimization of angle steel, we can see that the temperature gradient of the angle steel is very uniform, and the temperature distribution in the width direction of the angle steel is symmetrical, and the maximum temperature gradient is 2 189 °C/m.

STUDY ON THE BEST METHOD OF CONTROLLED COOLING FOR ANGLE STEEL

In the process of angle steel controlled cooling, the spray density and spray speed are the main factors that cause the temperature change of each part of angle steel. In this paper, the spray density and spray speed are selected as the design variables when optimizing the cooling mode of angle steel. We set the spray densities of the top of angle steel as W1, the middle of angle steel as W2, the bottom of angle steel as W3, and their constraint ranges are shown in Table 1. The purpose of controlled cooling process of angle steel is to promote the rapid transformation of austenite. In a short time, the angle steel is cooled to a reasonable temperature range, so as to obtain a more uniform temperature field and a good microstructure.

Therefore, the reasonable temperature range and the maximum temperature gradient after controlled cooling are selected as the state variables of optimal design. The range of reddening temperature of angle steel is 650 °C ≤T_end ≤700 °C. In order to get more uniform temperature field and smaller temperature gradient, the maximum temperature difference is taken as the objective function of design optimization. At the same time, the maximum temperature difference is further reduced.

The zero order method is used to optimize the temperature field of angle steel, and the optimization calculation is completed in the opt processor of ANSYS[5]. The comparison of parameters before and after optimization is shown in Table 2.

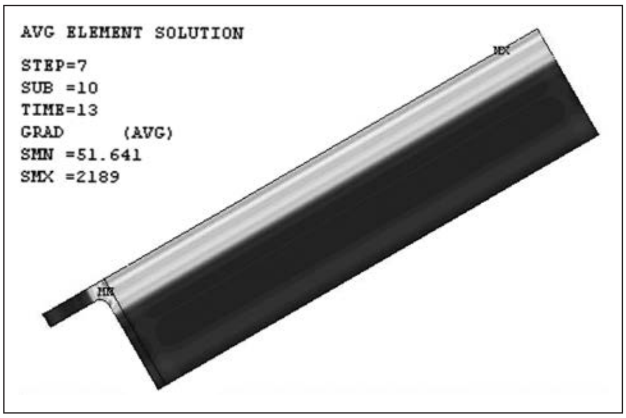

Figure 2 The temperature gradient before optimization

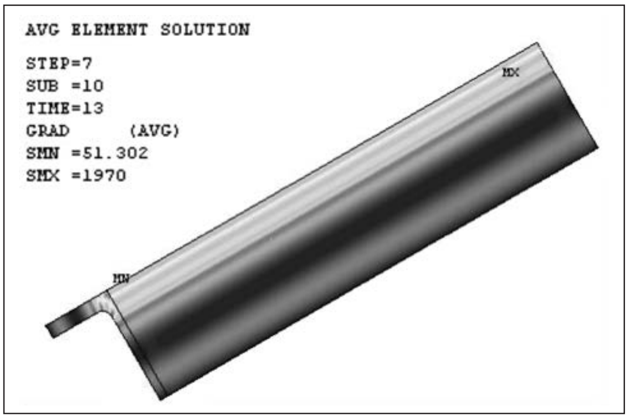

Figure 3 The temperature gradient after optimization

Table 1 **The restrict range of design variable**

spray densities	minimum value / L·m^{-2}·min^{-1}	maximum value / L·m^{-2}·min^{-1}
W1	900	1 200
W2	1 550	1 700
W3	2 500	3 000

Table 2 **The parameter contrast after optimization**

design variable	W1	W2	W3	velocity/ m·s^{-1}
before optimization	1 160	1 570	2 980	10
after optimization	1 076,1	1 673,5	2 977	9,2

Figure 3 is the temperature gradient after optimization of the angle steel. After optimization design, the maximum temperature gradient value decreased from 2 189 °C/m to 1 970 °C/m, decreased by 219 °C/m. And after the optimization, the maximum temperature gradient at the end of controlled cooling is lower than that before optimization. It shows that the temperature change rate along the normal direction of the isotherm decreases and the temperature distribution is more uniform.

CONCLUSION

Using ANSYS finite element analysis software, the temperature gradient distribution of angle steel can be calculated accurately. The best method of controlled cooling is: The spray density at the top of angle steel is 1 076,1 L·m^{-2}·min^{-1}, the middle of angle steel is 1 673,5 L·m^{-2}·min^{-1}, and the bottom of angle steel is 2 977 L·m^{-2}·min^{-1}, the water velocity is 9,2 m·s^{-1}. By optimizing the temperature field of angle steel during controlled cooling, the maximum temperature difference after controlled cooling can be reduced, so that the temperature distribution is more uniform. Through the calculation method and data analysis in this paper, it has a very important guiding significance for the reasonable customization of angle steel controlled cooling process, and also provides a theoretical basis for the research of other section steel controlled cooling.

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Note: The responsible translator for English language is L. Y. Huang, Anshan, China