Study of Numerical Method of Synthetical Surface Heat Transfer Coefficient on Rail during Spraying Process

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***Abstract*—In order to get precise synthetical heat transfer coefficients, the synthetical surface heat transfer coefficients on rail are calculated respectively by Two-point method, Three-point method and Whole method during spraying process, taken into the calculation model to get the cooling curve to compare with the experimental value. The cooling curve got from the synthetical heat transfer coefficient calculated by the Whole method is close to the experimental value and in line with actual situation**

Keywords-Numerical method, Synthetical heat transfer coefficient, Rail

I. INTRODUCTION

Heat transfer coefficient is an important parameter for spraying process about rail, which directly affects the rate of rail temperature changes and tissue transition. In recent years, researchers[1-8] have done a lot of researches about the calculation method of heat transfer coefficient, but most of them researched some components which could be regarded as an one-dimensional problem, for example column, cylinder and square plate, and didn't give a specific process of calculating heat transfer coefficient. Based on the previous researches, regarding rail as the researched object, synthetical surface heat transfer coefficients on rail calculated by three kinds of numerical methods, were taken into the calculation model to get a cooling curve to compare with the experimental value.

II. EXPERIMENTAL

In this paper, a U75V rail is adopted. Its specification is 60kg/m, length 500 mm, and carbon content between 0.74% and 0.77%. It belongs to hypereutectoid steel. The thermal physical parameters[9] of rail U75V are shown in Table I.

TABLE I. THE THERMAL P TABLE I. THE THERMAL PHYSICAL PARAMETERS OF RAIL U75VHYSICAL PARAMETERS OF RAIL U75V

Temperature /°C	20	100	200	300	400	500	600	650	720	750	850	950
Specific heat / $W\cdot m^{-1}\cdot °C^{-1}$	41.6	39.7	37.5	35.0	32.3	30.0	29.0	28.1	34.8	23.4	25.7	26.9
Conductivity /$J\cdot kg^{-1}\cdot °C^{-1}$	473	482	498	513	529	599	635	756	1080	577	624	720
Expansion cofficient /10^{-6}	15.3	15.75	15.9	16.25	16.5	16.75	16.8	21.5	21.0	21.4	21.45	18.5

Firstly, half a meter of the rail was heated about 4～5 hours till 964.4℃ in the heating furnace, then moved into cooling equipment. The distance between 3 nozzles above the rail and upper surface of rail was 200mm, and there were also 3 nozzles at each side and the bottom of the rail as shown in Figure 1. The rail had sprayed for 200s under flow rate of water was 0.600 m^3/h and air pressure 0.24MPa. A thermocouple was put on 1# point which distanced 10mm to the upper surface center of rail. The thermocouple was used for real-time measurement to temperature, and conveyed to ADAM acquisition card to gain a cooling curve as shown in Figure 2. The cooling curve would be used to calculate synthetical surface heat transfer coefficients on rail by three kinds of numerical methods.

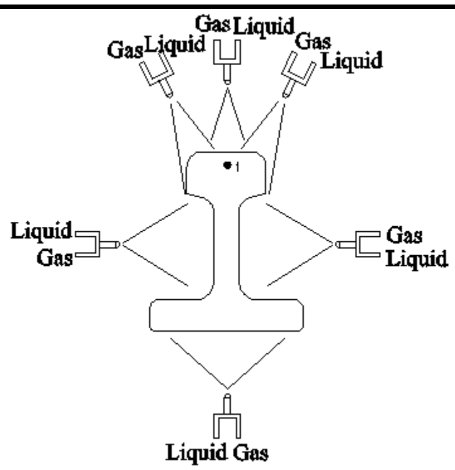

Figure 1. Nozzles around rail

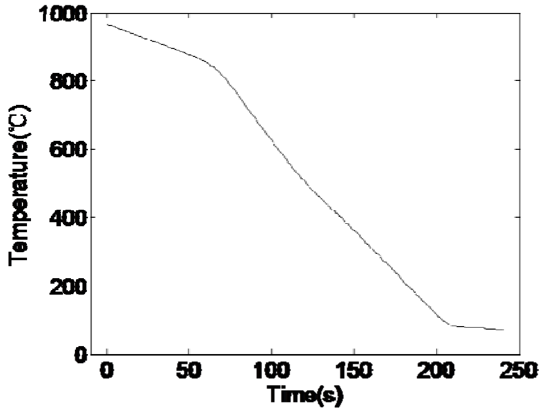

Figure 2. Cooling curve

III. ANALYSIS

A. Physical model

Based on the finite element software of ABAQUS and its scripting language called Python, a program which calculated synthetical surface heat transfer coefficient about rail was written. The program created the finite element model of rail, put into the conductivity, expansion cofficient, specific heat, mass density 7850kg/m^3, solidus temperature 570℃, liquidus temperature 620℃and latent heat 78200J, set up an initial temperature 964.4℃ on the rail, the temperature of the water mist 20℃and heat transfer boundary conditions on the surface of the rail model in addition to two cross-sections and a symmetry plane of the rail model. The model of rail was shown in Figure 3.

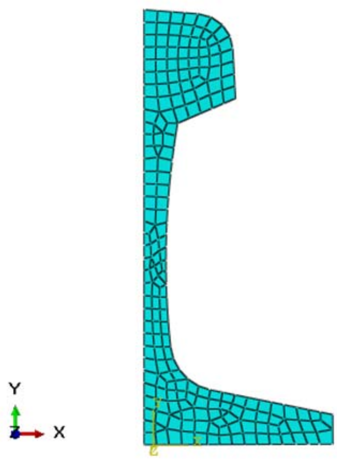

Figure 3. Finite element model of rail

B. Numerical method

The cooling curve in Figure 2 was divided into several steps to calculate a synthetical heat transfer coefficient of each step. The numerical method of each step is shown as follows.

According to the range of the synthetical surface heat transfer coefficient on rail during spray process, an initial value h_1 was given for the synthetical heat transfer coefficient which the first step corresponded to before the model of rail was calculated. Temperature field was calculated. Temperature value T_1 of 1# point was extracted from calculated result. An initial value $h_2 = h_1+50$ was again given for a synthetical heat transfer coefficient which the first step corresponded to before the model of rail was calculated. Temperature field was calculated. Temperature value T_2 of 1# point was extracted from calculated result. Compare it to the experimental value to make sure that the range of temperature error met the requirements. If the range of temperature error met the requirements, the calculation would be stopped. If the range of temperature error didn't meet the requirements, the calculation would be continued until meeting the requirements. Calculating flow chart of each time step was shown in Figure 4.

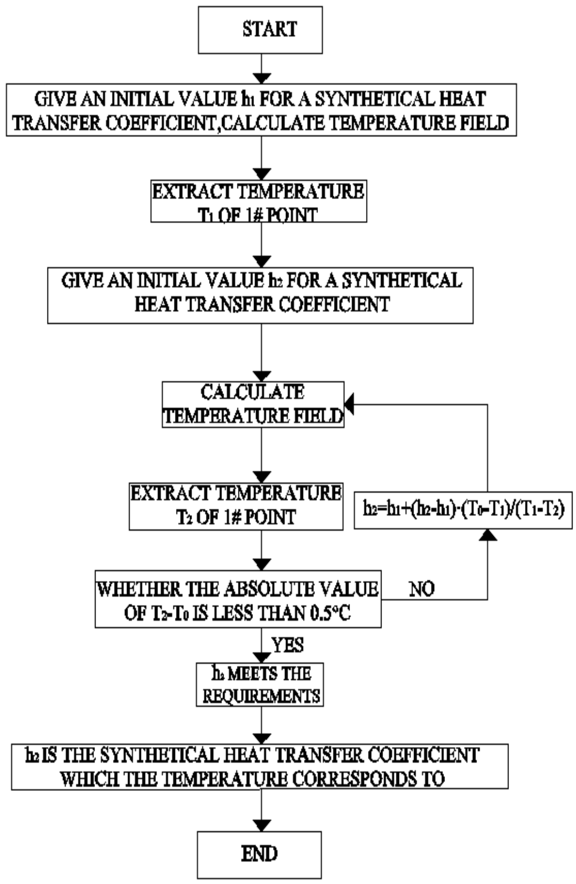

Figure 4. Calculating flow chart of each step

Based on the calculating flow path of each step, the synthetical heat transfer coefficients of all steps were calculated. According to the different calculating flow path of them, the numerical method was divided into two-point method, three-point method and whole method. The three kinds of numerical methods were shown as following.

Two point method: the synthetical heat transfer coefficient of each step is according to the above calculating flow path; the synthetical heat transfer coefficient of the step N is taken into the calculation model to calculate the calculation model from step N to step N+1 when the synthetical heat transfer coefficient of step N+1 is calculated. In this way, the synthetical heat transfer coefficient which temperature of each step corresponds to is calculated.

Three point method: the synthetical heat transfer coefficient of each step is according to the above calculating flow path; the synthetical heat transfer coefficients of step N and step N-1 are taken into the calculation model to calculate the calculation model from step N-1 to step N+1 when the synthetical heat transfer coefficient of time step N+1 is calculated. In this way, the synthetical heat transfer coefficient which temperature of each step corresponds to is calculated.

Whole method: the synthetical heat transfer coefficient of each step is according to the above calculating flow path; the synthetical heat transfer coefficients of the above N steps are taken into the calculation model to calculate the calculation model from step 1 when the synthetical heat transfer coefficient of step N+1 is calculated. In this way, the synthetical heat transfer coefficient which temperature of each step corresponds to is calculated.

IV. RESULTS AND DISCUSSION

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The results presented in Figure 5 indicated the variety law of synthetical heat transfer coefficients and comparison of them between three kinds of methods. Synthetical heat transfer coefficients were changed with the change of temperature, and had two extremums in temperature ranges of 560℃~660℃and 80℃~140℃. It displayed that it happened phase transition in temperature ranges of 560℃~660℃. The variation range of synthetical heat transfer coefficients calculated by Two-point method was 100~6000 W/(m^{-2}·℃), wider and unsteady. 0ne extremum of synthetical heat transfer coefficients calculated by Two-point method was about 6000W/(m^{-2}·℃) at the temperature 114.9℃, the other was about 2800W/(m^{-2}·℃) at the temperature 626.5℃. The variation range of synthetical heat transfer coefficients calculated by Three-point method was 100~4890 W/(m^{-2}·℃), wide and unsteady. 0ne extremum of synthetical heat transfer coefficients calculated by Three-point method was about 4900W/(m^{-2}·℃) at the temperature 95.8℃, the other was about 2400W/(m^{-2}·℃) at the temperature 626.3℃. The variation range of synthetical heat transfer coefficients calculated by Whole method was 100~3180 W/(m^{-2}·℃), narrow and steady. 0ne extremum of synthetical heat transfer coefficients calculated by Whole method was about 3200W/(m^{-2}·℃) at the temperature 95.8℃, the other was about 1265W/(m^{-2}·℃) at the temperature 594℃. It could be seen that synthetical heat transfer coefficients calculated by Whole method was narrower and steadier.

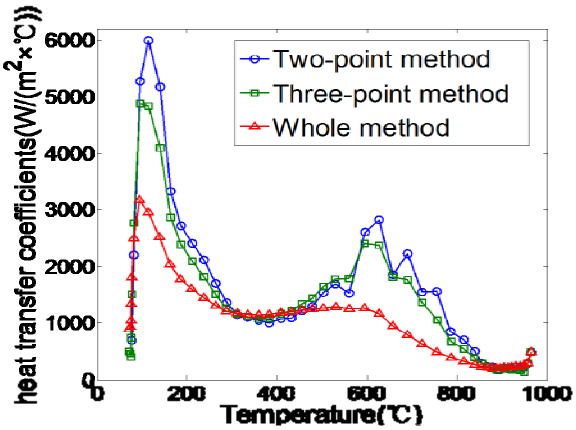

Figure 5. Comparison of synthetical heat transfer coefficient between three kinds of methods

Synthetical heat transfer coefficients in Figure 5 were taken into the rail model. Cooling curves were calculated to compare with experimental value respectively. They were respectively shown as Figure.6, Figure 7 and Figure 8.

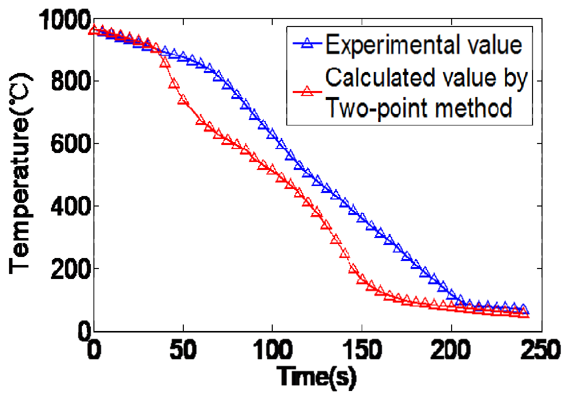

Figure 6. Comparison of temperature between calculated value by Two-point method and the experimental

As shown in Figure 6, a cooling curve which synthetical heat transfer coefficients calculated by Two-point method taken into the model of rail is basically agree with the experimental value in the periods of 0~35s and 205~240s, while differs from the experimental value in the period of 35~240s.This period is about seventy percent of the total cooling time. The temperature error value is 195℃ at the 150th second.

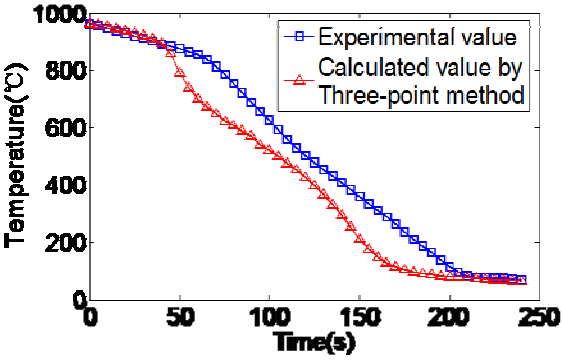

Figure 7. Comparison of temperature between calculated value by Three-point method and the experimental value

As shown in Figure 7, a cooling curve which synthetical heat transfer coefficients calculated by Three-point method taken into the model of rail is basically agree with the experimental value in the periods of 0~40s and 205~240s, while differs big from the experimental value in the period of 40~205s.This period is about seventy percent of the total cooling time. The temperature error value is 163℃ at the 160th second.

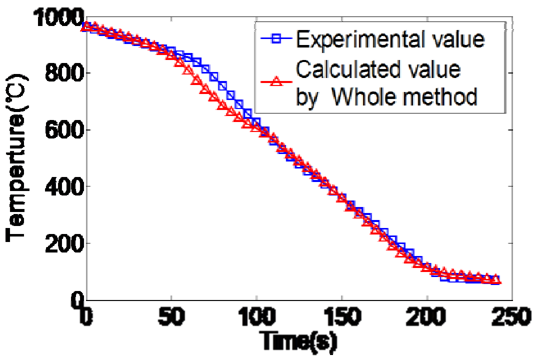

Figure 8. Comparison of temperature between calculated value by Whole method and the experimental value

As shown in Figure 8, a cooling curve which synthetical heat transfer coefficients calculated by Whole method taken into the model of rail is basically agree with the experimental value in the periods of 0-50s and 100-240s, while differs big from the experimental value in the period of 50~100s.This period is about twenty percent of the total cooling time. The temperature error value is 75℃ at the 160th second.

It is noted obviously that the cooling curve gotten by the Whole method have narrower and smaller error rang, and is more agree with the experimental value compared with the cooling curves gotten by Two-point method and Three-point method.

V. CONCLUSIONS

By comparison of synthetical heat transfer coefficients between three kinds of numerical methods, the variation range of calculated synthetical heat transfer coefficients by Two-point method and by Three-point method is wide and unsteady, while the variation range of calculated synthetical heat transfer coefficients by the Whole method is narrower and steadier. The cooling curve gotten by Whole method has narrower and smaller error rang, and is more agree with the experimental value compared with the cooling curves gotten by Two-point method and Three-point method. Whole method is a better method by which synthetical heat transfer coefficients are calculated. This method isn't used to only rail but also other kinds of steel during spraying process.

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