Surface Heat Transfer Coefficient’s Calculation and Analysis on Atmospheric High Speed Aerosol Quenching

Liuchuang WEI*, Yong YANG2, Ping WEI2, Hongyu CHEN2

1Faculty of automatic Control and Mechanical Engineering, Kunming University, Yunnan Kunming 650214, China
2Faculty of urban and rural construction & Engineering Management, Kunming University, Yunnan Kunming 650214, China
*Corresponding author’s e-mail: weiliuchuang@126.com

Abstract. Atmospheric aerosol quenching at a high speed is a new quenching process. Each condition is equivalent to a new type of quenching medium. In this study, quenching experiments with atmospheric high speed aerosol were carried out. In this paper, the surface integrated heat transfer coefficient of the specimen during the quench process is reverse solved with FEM software DEFORM and FORTRAN program based on nonlinear estimation method respectively, and the results of inverse heat transfer calculation are analyzed.

1. Research significance about surface coefficient of heat transfer
Atmospheric aerosol quenching at a high speed is a new quenching process. Each condition is equivalent to a new type of quenching medium. In order to in-depth knowledge the temperature field of inside workpiece when the quenching cooling, We must obtain the Surface heat transfer coefficient. In recent years, Research results show that experimental conditions are extremely sensitive to the measured results of surface heat transfer coefficient. Now for the Study of the surface heat transfer coefficient, we devote to seek a method which the experiment combined with numerical calculation [1].
In recent years, scholars at home and abroad mainly studied the following aspects:

● The influence factors of surface heat transfer coefficient;
● Calculating methods of surface heat transfer coefficient;
● Application software development about numerical calculation, etc.

2. Calculating methods of surface heat transfer coefficient
According to Newton’s law of cooling, the calculation formula of heat-flow density can be listed as follows:

\[ q = H_f \times (T_w - T_c) \] (1)

In Eq. 1, q represents heat-flow density; the unit of q is W/m2. Hf represents the surface heat transfer coefficient. The unit of Hf is W/(m2·℃). Tw represents the temperature of the object boundary. The unit of Tw is ℃. Tc represents the temperature of the object surface which produces convective heat transfer medium. The unit of Tc is also ℃. For the process of quenching cooling at some point, we assume that Tw and Tc are known. If q is obtained, we will know the Hf.
According to this train of thought, we can design a test which makes the heat transfer problem is simplified. And then by solving heat conducting differential equation, we can obtain the surface heat transfer coefficient during quenching. Predecessors, according to the study of surface thermal conductance through experimental research, theoretical research and calculation method research, designed the different measuring methods. They can be shown as follows [2, 3]:

- The direct solving method of surface temperature;
- Double measuring difference solution;
- Inverse heat conduction solution.

3. Experimental program
The sample of this experiment is cylindrical. The diameter of sample is 20 mm, and the length is 60 mm. Steel used in the experiment is T10. Two punches are made with drill press equipment at the bottom. One of the punches is located in the center of the circle. The other one is near the side surface. The depth of the punch is 30 mm. They are used to decorate thermocouple, so that we can obtain the cooling curves of the center of cross section and close to the surface during the process of quenching cooling. Sample processing and thermocouple decoration is shown in Figure 1.

![Figure 1. sample processing and thermocouple decoration](image)

4. Constitute inverse heat conduction program
The module interface of inverse heat conduction about DEFORM-3D is easy to operate. It does not depend on the location of the measuring point. We can solve complicated three-dimensional inverse heat conduction. Considering the material, latent heat of phase change and workpiece size of the experiment, we can leave out the influence about latent heat of phase change. Technical route of inverse heat conduction about DEFORM-3D can be shown in Figure 2 [4].

Considering the symmetry, we can just set up a quarter model. When defining material property, we can select material type in the material library depending on the type of material or make the analogy of materials according to the carbon content. According to the experimental conditions, the heat preservation temperature is settled at 800 °C and coordinates data of measuring point are inputted. Functional form of surface the heat transfer coefficient does change with temperature.

In order to investigate the reliability of the surface heat transfer coefficient calculated by DEFORM finite-element software, we adopt nonlinear estimation method based procedures to verify. As we all know the nonlinear estimation method’s algorithm is mature, and the precision is reliable.
5. Inverse heat transfer calculation result

Using inverse heat transfer about DEFORM-3D, the heat-transfer coefficient was calculated for the following conditions. After calculations through DEFORM-3D, the curve of the surface heat transfer coefficient changing with temperature can be obtained. The curves can be shown in Figure 3-6.

Figure 3. water 100 ml/min, nitrogen pressure 0.5 MPa

Figure 4. water 100 ml/min, nitrogen pressure 2.5 Mpa

Figure 5. water 1100 ml/min, nitrogen pressure 0.5 MPa

Figure 6. water 1100 ml/min, nitrogen pressure 2.5 Mpa
The results above cannot really reflect the heat-transfer situation of the end face because of the fewer temperature measuring points. In consideration of the cooling surface is small and not the main part of heat exchange, the axisymmetric two-dimensional problem can be further simplified to the axisymmetric one-dimensional problem without considering the heat conduction at the end.

The result of solving calculation with DEFORM-2D is shown in Figure 7 (a), and the result of solving calculation based on FORTRAN 90 program with nonlinear estimation method is shown in Figure 7 (a).

According to the literature [1], Figure 8 shows the inverse heat conduction calculated surface heat transfer coefficient curve on T10 steel specimen quenched by water and spindle oil calculated with FORTRAN90 program based on the nonlinear estimation method. In the curve, surface heat transfer coefficient changed with the surface temperature decreased.

6. Conclusion
Through the analysis of calculation results, we can get the following conclusions:
Using several kinds of quenching medium to quench, nonlinearity of surface temperature and surface heat transfer coefficient is obvious. In the previous literature, the heat-transfer coefficient is assumed to be constant, this will cause a greater error.

Surface heat transfer coefficient of atmospheric aerosol quenching at a high speed is relatively stable. With the increase of water flow, it is more stable. Because the cooling surface is smaller, it is not the main heat transfer area. So we can conclude that the impact on the quenching process has been small.

Surface heat transfer coefficient of atmospheric aerosol quenching at a high speed varies with the change of temperature. In the beginning of quenching, surface heat transfer coefficient is high and the heat exchange is strong. With the decrease of temperature, heat which pearlite transforms release. It will lead to decrease of the calculated value. Platform can be shown in figures.

For the atmospheric aerosol quenching at a high speed, we can obtain the change of heat transfer coefficient according to the different water flow and different gas flow.

The heat transfer coefficient on the side of the specimen with high pressure and high speed fog is fluctuating with temperature. Figure 7 shows that the comprehensive heat transfer coefficient on the side of the specimen is relatively gentle to the initial quenching stage, and a peak value of the heat transfer coefficient on the side of the specimen appears at about 200 C, which accelerates the cooling process. This may be due to the instability of the temperature measurement in the low-temperature zone of the K-type thermocouple during the rapid cooling process.

The heat-transfer coefficient curves of atmospheric pressure and high speed spray quenching are different from those of water quenching and ingot oil quenching, which shows that the quenching cooling characteristics of atmospheric pressure and high speed spray quenching are different from those of water quenching and ingot oil quenching, and it is a new quenching cooling form.

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