Prediction of Microstructure and Thermophysical Properties of Steel for Brake Discs

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Abstract: With the increasing speed of high-speed trains, the brake disc heat load has also been increasing, particularly during emergency braking. Therefore, to address such issues, strict requirements for brake disc materials are suggested. The microstructure and mechanical properties of steel for brake discs was investigated. Based on the material thermodynamic calculation software JMatPro, the equilibrium phase composition, hardenability and other thermophysical parameters of steel for brake discs are calculated and predicted. The paper also calculates and draws the continuous heating austenitizing (TTA) curve and continuous cooling transformation (CCT) curve of the steel for brake discs, and predicts the martensite transformation temperature and other relevant material parameters, in order to provide theoretical basis for the heat treatment process.

Keywords: high-speed train, brake disc, cast steel, microstructure, thermophysical properties.

1 Introduction

The brake disc is the core component of the brake device, which plays a vital role in the safe running of the high-speed trains[1-3]. However, with the increase of train speed, the brake disc needs to have sufficient strength, such as room temperature/low temperature plastic toughness, high temperature strength and plasticity, thermal fatigue performance, high temperature wear performance, thermal conductivity, etc., to meet the use of high-speed trains[4-8].

2 Experimental procedure

The element composition of low alloy cast steel for brake disc of high-speed train is shown in Table 1.

Table 1. Chemical composition of low-alloy cast steel for high-speed iron brake disc (mass fraction /%)

C	Si	Mn	Cr	Ni	Mo	Al	Cu
0.23	0.44	1.07	0.87	0.94	0.60	0.03	0.09

The test material is heat treated to change its matrix structure, and then the relationship between its structure and properties is investigated. The heat treatment process parameters of the material are shown in Fig.1 The microstructure of the sample after heat treatment is observed.

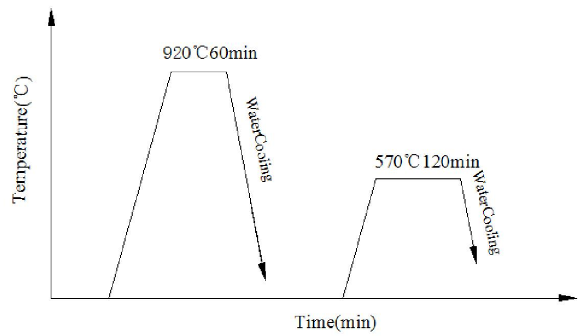

Fig.1 - Heat treatment process parameters of steel used for high-speed rail brake disc.

3 Result and discussion

Tempered sorbite was formed after tempering the quenched structure of the experimental steel at high temperature. The quenched lath martensite recrystallized to form equiaxed grains. Carbide dispersion distribution. The volume fractions of ferrite, cementite and carbide were 61%, 38.8% and 0.2%, respectively. Jmatpro software was used to calculate the equilibrium phase composition of the cast steel from room temperature to 1600℃.The equilibrium precipitated phase in brake disc steel is: M_2 (C,N), M (C,N), M_7C_3, MNS, M_6C, $M_{23}C_6$. At room temperature, the structure content of the low-alloy cast steel used for the brake disc is respectively: ferrite (F) 95.51%, M_2 (C,N)phase 1.34%, G phase (a special intermetallic compound containing Ni and Si elements) 1.56%, M_7C_3 phase 1.15% and about 0.24% cementite. The Young's modulus and density of low alloy cast steel used for high iron brake disc are negatively correlated with temperature. A maximum of 212.66GPa and 7.83g/cm^3 occurred at room temperature. When the cast steel melts and the solid-liquid phase changes, both values decrease significantly. Poisson's ratio of cast steel is positively correlated with temperature and has a minimum value of 0.289 at room temperature. When the specific heat capacity of cast steel increases from room temperature to melting point, it decreases first and then increases. It has a maximum value of 62.42W/(m·K) at 20℃ and a minimum value of 25.89W/(m·K) at 793.41℃In addition, the analysis of equilibrium phase diagram, with the increase of temperature, the G phase in the low-alloy cast steel material used in the brake disc dissolves rapidly, resulting in a rapid decline in specific heat capacity. At

793.41℃, the dissolution of ferrite and the formation of austenite gradually increase the specific heat capacity of cast steel. TTA diagram of low alloy cast steel for high-speed rail brake disc is shown in Fig 2. According to the TTA diagram, Ac1, Ac3 and austenite homogenization temperatures all increase with increasing heating rate. The CCT curve of cast steel is drawn according to thermodynamic simulation, as shown in Fig 2. It can be seen that the initial martensite transition temperature (Ms) is 352.45℃, the temperature is 317.81℃ when the transformation to 50% martensite, and the temperature decreases to 237.37℃ when the transformation fraction is 90%. The initial transition temperature of bainite (B) is 542.7℃. The perlite (P) transition temperature is 668.39℃.

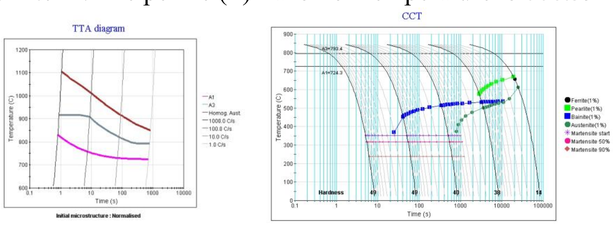

Fig.2 - TTA diagram and CCT curve of low alloy cast steel for brake disc of high speed train

4 Conclusion

In this paper, the microstructure and properties of steel used for high-speed train brake discs are preliminarily analyzed, and the thermophysical properties of low-alloy cast steel used for high-speed train brake discs are predicted and analyzed based on thermodynamic simulation software. According to the calculation results, the equilibrium phase composition diagram and CCT curve of this steel at room temperature are obtained. In order to provide guidance for the casting of the cast steel and the formulation of subsequent heat treatment parameters, the conclusions are as follows:

(1) Tempered sorbite is formed in low alloy cast steel for high-speed train brake disc after quenching structure is tempered at high temperature.

(2) At room temperature, the equilibrium structure and content of low-alloy cast steel used for high-speed train brake disc are: ferrite (F) 95.51%, M_2(C,N) phase 1.34%, G phase 1.56%, M_7C_3 phase 1.15% and about 0.24% cementite.

(3) Density and Young's modulus were negatively correlated with temperature, and Poisson's ratio was positively correlated with temperature. The specific heat capacity of low-alloy cast steel used for brake discs of high-speed trains decreases first and then increases with the increase of temperature.

(4) The calculation of CCT curve shows that when the cooling rate of cast steel is greater than 0.5℃/s, martensite phase precipitation, the initial martensite transformation temperature (Ms) is 352.45℃, the temperature is 317.81℃ when the transformation to 50% martensite, and the temperature decreases to 237.37℃ when the transformation fraction is 90%. The initial transition temperature of bainite (B) is 542.7℃. The perlite (P) transition temperature is 668.39℃.

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