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ISSN 0543-5846
METABK 63(3-4) 377-379 (2024)
UDC – UDK 669.15.26:621.785:536. 425: 536.54:536.77 = 111

KINETICS ANALYSIS OF QUENCHING PHASE TRANSFORMATION OF 1Cr13 STEEL BY THERMAL ANALYSIS

Received – Primljeno: 2024-01-10
Accepted – Prihvaćeno: 2024-02-28
Original Scientific Paper – Izvorni znanstveni rad

Differential scanning calorimetry (DSC) was used to study the transformation process of 1Cr13 steel under quenching condition. The DSC curves were measured from 1 050 °C to room temperature at the cooling rate of 10, 20, 30, 50 °C /min, respectively. The Flynn-Wall-Ozawa method was used to obtain the activation energy of the transformation process of 1Cr13 steel under quenching condition. The kinetic mechanism functions of the transformation process of 1Cr13 steel under quenching condition were also investigated by Criado-Ortega methods. The results show that the activation energy is related to the phase transition fraction. It means the transformation process of 1Cr13 steel under quenching condition is not a simple one-step reaction but a complex multi-step reaction.

Keywords: 1Cr13 steel, quenching, transformation, differential scanning calorimetry, the activation energy

INTRODUCTION

Quenching is an important process in the heat treatment process of metal materials, which changes the structure and properties of materials by rapidly cooling the material to make it undergo phase change[1,2]. The phase transition of materials is a complex process during in quenching process. When the material is heated to a certain temperature, the atoms begin to move and gradually lose their ordered structure, forming a liquid state. In the quenching process, the rapid rate of cooling prevents the atoms from being reordered, resulting in an amorphous or metastable crystal structure of the material. The study of quenching kinetics can help us to better understand and control the quenching process, so as to optimize the properties of materials. The study of quenching kinetics is of great significance for optimizing the properties of materials. Through the study of quenching kinetics, the optimum quenching process parameters can be determined to achieve the best microstructure and properties of the material[3,4]. At the same time, the study of quenching dynamics can also guide the design and preparation of materials, and realize the customization of material properties[5].

In this paper, thermal analysis method was used to investigate the process of phase transformation for quenching of 1Cr13 steel. The differential scanning calorimetry (DSC) curve and phase transformation temperature were obtained. The activation energy of the phase transformation for quenching of 1Cr13 steel was achieved by Flynn-Wall-Ozawa method. The kinetic mechanism function of this process transformation were obtained by Criado-Ortega method, which provided a theoretical basis for further exploring the phase transformation mechanism of quenching process of 1Cr13 steel.

EXPREIMENT AND RESULT

The size of sample was about 2 mm of thickness and a width of about 2,5 mm, which is made by the linear cutting machine. The labsys synchronous was carried out in the experiment. The temperature range is from ambient to 1 200 °C, with heating rate from 0.1 to 50 °C/min. For experiments carried out under cooling conditions, the instrument was programmed to heat the sample from room temperature to 1 050 °C at a constant heating rate 10 °C/min. Subsequently, The temperature drops to room temperature at a cooling rate. Four cool-

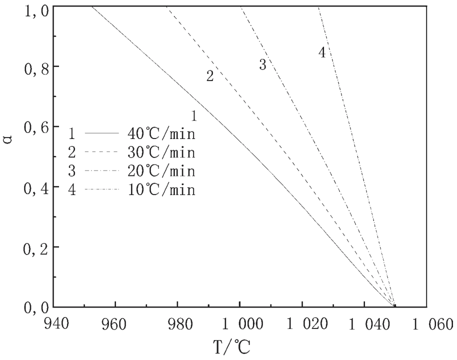

Figure 1 The dependence of phase transition fraction on temperature

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ing rate programs are studied: 10, 20, 30 and 50 °C/min. The phase transition fraction was calculated based on the data of the enthalpy at different cooling rates[6].The dependence of phase transition fraction on temperature is illustrated in Figure 1.

KINETICS ANALYSIS

The activation energy

The activation energy can be determined from the Flynn-Wall-Ozawa method[7]. The equation is shown in the following.

$$\lg\beta = \lg\left(\frac{AE}{Rg(\alpha)}\right) - 2,315$$

$$-0,4567\frac{E}{RT} \qquad (1)$$

Where, A is the pre-exponential factors, T is temperature, $g(\alpha)$ is the kinetics mechanism function of the phase transformation process, α is phase transition fraction for the quenching process, E is activation energy, R is gas constant, and β is cooling rate.

As seen from Eq. (1), when the α is a constant value, $g(\alpha)$ is also a constant value. Therefore, by making lg β–1/T curve, E under different phase transition fraction could be determined according to the curve's slope. The dependence of the activation energy on the phase transition fraction is shown in the Figure 2.

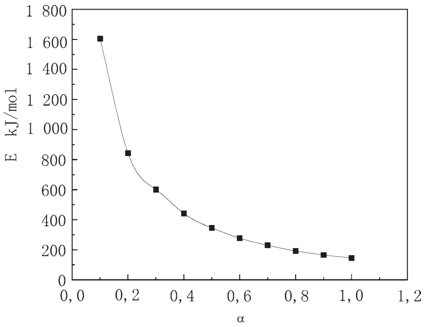

Figure 2 The dependence of activation energy on phase transition fraction

As seen from the Figure 2, the value of the activation energy varies with the phase transition fraction, indicating that the transformation process of 1Cr13 steel under quenching condition is not a simple one-step reaction but a complex multi-step reaction. At the initial stage of phase transformation, the value of the activation energy is large, probably because the energy barrier needed to overcome for the nucleation and growth of the new phase is large. With the increase of phase transition fraction, the value of the activation energy decreases gradually. The possible reason can be that the existence of new phase provides location for the nucleation of new phase and makes nucleation easier.

The mechanism function

In order to obtain the kinetic mechanism function of the phase transformation for quenching of 1Cr13 steel, experimental data were analyzed by Criado-Ortega method[8]. The equation is shown in the following

$$\ln[-\ln(1-\alpha)] = -n\ln\beta - 5,33n$$

$$+n\ln\frac{AE}{R} - 1,0516\frac{E}{RT} \qquad (2)$$

Where n is the exponent of the kinetics mechanism function.

It could be seen that the last three terms on the right side of Eq.(2) were constant values if the T was chosen under different cooling rates. Therefore, by making ln[–ln(1–α)]–lnβ curve, the n value could be calculated through the curve's slope, and the corresponding kinetic mechanism function $g(x)$ = $[-\ln(1-\alpha)]^{1/n}$ could be obtained. The results are shown in theTable 1.

Table 1 **the value of n calculated by Eq. (2)**

T/°C	n	Average of n	Mechanism function
1 030	0,44322	0,5	$[-\ln(1-\alpha)]^2$
1 031	0,4425		
1 032	0,44488		
1 033	0,45351		
1 034	0,46791		
1 035	0,48611		
1 036	0,51749	0,6	$[-\ln(1-\alpha)]^{5/3}$
1 037	0,55426		
1 038	0,58982		
1 039	0,64116	0,7	$[-\ln(1-\alpha)]^{10/7}$
1 040	0,70256		
1 041	0,768		
1 042	0,8233		
1 043	0,90126	0,9	$[-\ln(1-\alpha)]^{10/9}$
1 044	0,97636		
1 045	1,0457	1,0	$-\ln(1-\alpha)$
1 046	1,11765		
1 047	1,20264	1,2	$[-\ln(1-\alpha)]^{5/6}$
1 048	1,27532		
1 049	1,40628		

As seen from Table 1, the n values corresponding to different temperatures are also different, which indicates that kinetic mechanism function of the phase transformation for quenching of 1Cr13 steel at different temperatures are different. It is further reveals that the quenching phase transformation of 1Cr13 steel process is a multi-step complex reaction. According to the kinetic mechanism function, the quenching phase transformation of 1Cr13 steel conforms to an accommodated nuclei production and nuclei growth model.

CONCLUSION

The activation energy of the phase transformation for quenching of 1Cr13 steel is dependence of the phase transition fraction at different cooling rates. The kinetics mechanism functions is different with the temperature range. We can concluded that the the phase transformation for quenching of 1Cr13 steel is not a simple one-step reaction. The kinetics mechanism functions for the the phase transformation for quenching of 1Cr13 steel obtained by Criado-Ortega method are $[-\ln(1-\alpha)]^2$, $[-\ln(1-\alpha)]^{5/3}$, $[-\ln(1-\alpha)]^{10/7}$, $[-\ln(1-\alpha)]^{10/9}$, $-\ln(1-\alpha)$, $[-\ln(1-\alpha)]^{5/6}$, respectively. The phase transformation for quenching of 1Cr13 steel conforms to an accommodated nuclei production and nuclei growth model.

Acknowledgements

The authors gratefully acknowledge the Liaoning Province Regional Joint Fund Project (2021-YKLH-02); The Liaoning Province Regional Joint Fund Project (2022-YKLH-15); General project of Liaoning Provincial Department of Education (LJKZ1198); Excellent Talents of Science and Technology in Yingkou Institute of Technology (RC201903). The project of Liaoning Provincial Key Laboratory of Energy Storage and Utilization (CNNK202304,CNNK202324).

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Note: The responsible translator for language English is
Y. H. Wang - Yingkou Institute of Technology, Liaoning, China.