

ANALYSIS OF TRANSFORMATION KINETICS OF 1035 STEEL AT DIFFERENT COOLING RATES

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In this paper, the enthalpy change of 1035 steel during phase transformation at different cooling rates was measured by differential scanning calorimetry (DSC). The activation energy of the phase transformation process was calculated by the equal conversion method, and the mechanism function of the process was also determined. The results shown that the value of the activation energy of phase transformation process varied with the transformation fraction, and the mechanism functions of transformation process are different in different temperature ranges, which are $-\ln(1-a)^{1/3}$ for ≥ 645 °C $-\ln(1-a)^{1/2}$ for 660-655 °C and $-\ln(1-a)$ for 650-645 °C respectively.

Keywords: 1035 steel; DSC; phase change; the activation energy; the transformation fraction

INTRODUCTION

The kinetics process of solid phase transformation directly affects the microstructure and structure of materials, and then determines their properties and service properties. Therefore, the study of solid state phase transition kinetics has always been a topic of common concern for high performance metal material preparation workers. The main task of studying the kinetics of solid phase transformation is to obtain the phase transition mechanism, activation energy and other kinetic parameters of the phase transition process by using the kinetic analytical method based on the established kinetic theoretical model. It is very important to establish an accurate dynamic model and a reasonable dynamic analysis method, in order to accurately predict and control the solid phase transition process. At present, Kolmogorov Johnson Mehl Avrami (KJMA) model is widely used in the study of dynamic models [1]. Since the model is based on the assumption of random distribution of crystal nuclei and isotropic growth, its dynamic parameters remain constant throughout the phase transition process. As a result, the model can not accurately describe the actual solid phase transition dynamics when dealing with the actual solid phase transition dynamics. Therefore, the KJMA kinetic model has been revising by some scholars in order to improve the applicability of the model in dealing with the actual solid phase transition dynamics [2-4]. The direct solution

method and fitting method are two commonly used analytical methods for studying solid phase transition. However, both of the two methods have their own advantages and disadvantages. The Kissinger method [5] and Ozawa method [6] are the most commonly used direct solution methods. The growth index and the activation energy of the phase change process can be obtained from the intercept and slope of the linear fitting results, and then the reaction mechanism can be determined. However, when this method is used for linear fitting, there is often a large deviation between the fitting results and the actual data, which makes the reliability of the determined dynamic parameters questionable [7]. For the fitting method, it is determine the kinetic parameters by directly fitting the classical model to a single experimental curve. However, this method assumes that the dynamic parameters are constants, which makes the dynamic parameters obtained by this method inconsistent with the actual dynamic behavior [8]. This makes the fitting method have limitations in practical application. In fact, the solid phase transition process is accompanied by the changing structure, composition and degree of ordering. It is usually involved complex physical and chemical processes such as solute diffusion, non random distribution of crystal nuclei and anisotropic growth. The changing of energy barrier between these physical processes, which result that the ever-changing path, products and morphology of phase transition.

In this paper, thermal analysis technology is used to study the phase transformation dynamics of 1035 steel, and a dynamic model based on the change of enthalpy during the phase transformation process of 1035 steel is established. Using the equal conversion fraction method to calculate the “variable activation energy” in the phase transformation process, determine the transfor-

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mation mechanism and structure formation law of 1035 steel, lay a foundation for people to go deep into the phase transformation of 1035 steel, and have extremely important theoretical and practical significance for the ultimate realization of the optimization of the structure, structure and properties of 1035 steel.

EXPERIMENT AND RESULT

At the first, use the wire cutter to cut the sample into primary sheets with a thickness of nearly 2,5 mm, and grind them into sheets with a thickness of about 2 mm and a width of about 2,5 mm. Labsys synchronous DSC was used in the experiment. The temperature measurement range is from ambient to 1 600 °C. The heating program is from 30 °C to 1 550 °C at a heating rate of 10 °C/min⁻¹, and then drops to room temperature at a cooling rate of 10 °C/min⁻¹, 20 °C/min⁻¹, 30 °C/min⁻¹, 50 °C/min⁻¹. In order to reduce the experimental error generated by the experimental system, the blank without sample shall be conducted first, and then the experiment with sample shall be conducted. In order to realize the experiment at the same starting temperature, the room temperature shall be raised to 30 °C for 10 minutes, and then the system shall be reset. Under different cooling rates, the relationship between the heat flow and temperature (800 °C- 500 °C) in the phase change process obtained in the experiment is shown in Figure 1.

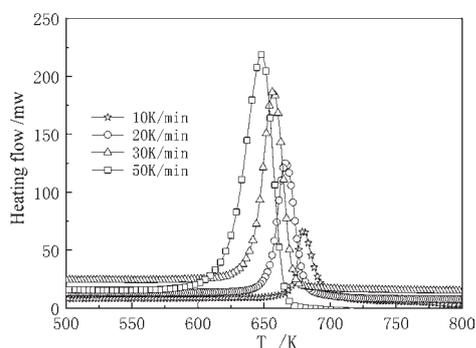


Figure 1 Relationship between heat flow and temperature at different cooling rates

Use ARL3460 direct reading light to detect the element composition of the sample, as shown in Table 1.

Table 1 Chemical composition / mas. %

Element	Chemical composition / mas. %
C	0,32~0,39
Si	0,17~0,37
Mn	0,50~0,80
S	≤0,035
P	≤0,035
Cr	≤0,25
Ni	≤0,30
Cu	≤0,25

KINETICS ANALYSIS

The conversion ratio (α) was calculated by the following formula:

$$\alpha = \frac{S_1}{S_0} \quad (1)$$

Where, S_1 is the partial area from phase transformation began to a certain temperature of the endothermic peak in the figure 1, S_0 is the area of the whole endothermic peak in the figure 1. The activation energy could be obtained by the Flynn-Wall-Ozawa method. The formula is shown in the following.

$$\lg \beta = \lg \left(\frac{AE}{Rg(\alpha_{DSC})} \right) - 2,315 - 0,4567 \frac{E}{RT} \quad (2)$$

Where, A is the pre-exponential factors, T is temperature, $g(\alpha)$ is the kinetics mechanism function of phase transformation related to α , E is activation energy, R is gas constant, and β is heating rate.

According to Eq.(2), when α is a constant value, $g(\alpha)$ is also a constant value. Therefore, by making $\lg \beta - 1/T$ curve, E under different conversion ratio could be calculated through the curve's slope. The relationship the E calculated by the Eq.(2) with the conversion ratio is shown in Figure 2.

It can be seen from Figure 2 that the transformation activation energy of 1035 steel first increases and then decreases with the increase of transformation fraction. When the conversion fraction is about 40 %, the activation energy value is 133 kJ/mol, and then gradually decreases with the increase of the conversion fraction. At the end of the phase transition, the value decreases to about 20 kJ/mol, and the activation energy value decreases by nearly 82 %. In the process of phase transformation, due to the existence of alloy elements in Table 1, the new phase nucleus is blocked in the process of nucleation, which leads to the increase of transformation activation energy with the increase of conversion fraction. When the new phase nucleus reaches a certain size, the energy learned during its growth is small, which makes the activation energy of phase transition decrease with the increase of the conversion fraction.

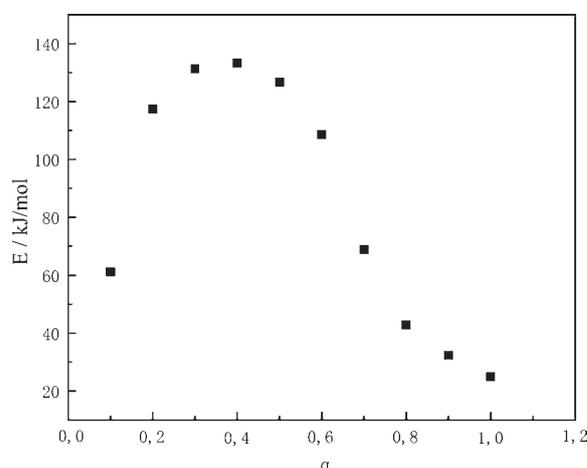


Figure 2 Relationship between activation energy and conversion fraction

In order to obtain the kinetic mechanism function, the Criado-Ortega method is used to analyze the experimental data. The theoretical equation of Criado-Ortega method is shown as the following.

$$\ln[-\ln(1-\alpha)] = -n \ln \beta - 5,33n + n \ln \frac{AE}{R} - 1,0516 \frac{E}{RT} \quad (3)$$

It can be seen from the Eq.(3), if the same temperature T was chosen under different cooling rates, the last three terms on the right side of Eq. 3 were constant values. Therefore, by making $\ln[-\ln(1-\alpha)] - \ln \beta$ curve, the n value could be calculated through the curve's slope, and the corresponding kinetic mechanism function could be obtained. The results are shown in the Table 2.

Table 2 The mechanism function calculated from Eq.(3)

T/°C	N	R	n	g(a)
665	-3,2960	0,89387	≈-3	$-\ln(1-a)^{1/3}$
660	-2,4103	0,90975	≈-2	$-\ln(1-a)^{1/2}$
655	-1,7854	0,92316		
650	-1,3439	0,96319	≈-1	$-\ln(1-a)$
645	-1,1361	0,98803		

According to the Table 2, The values of n are under different temperatures, it is indicated that kinetic mechanism function are different with the temperature. Therefore, the phase transformation process is a multi-step complex reaction. the phase transformation process can be divided into three stages. Based on the kinetic mechanism functions commonly used in solid-state reaction[10], the kinetic mechanism functions of the above four stages are respectively $-\ln(1-\alpha)^{1/3}$, $-\ln(1-\alpha)^{1/2}$, $-\ln(1-\alpha)$. According to the kinetic mechanism function, it concluded that the phase transformation of 1035 steel conforms to an accommodated nuclei production and nuclei growth model.

CONCLUSION

At different cooling rates, the activation energy of transformation process of 1035 steel first increases and then decreases with the increase of conversion fraction. It is indicated that the phase transformation of 1035 steel is not a simple one-step reaction. The kinetics mechanism functions of 1035 steel phase transformation obtained by Criado-Ortega method are $-\ln(1-\alpha)^{1/3}$, $-\ln(1-\alpha)^{1/2}$, $-\ln(1-\alpha)$, respectively. The phase trans-

formation of 1035 steel conforms to an accommodated nuclei production and nuclei growth model.

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Note: The responsible translator for language English is associate professor W. H. Ma - Yingkou Institute of Technology, Liaoning, China. The translator has translated the manuscript (Analysis of transformation kinetics of 1035 steel at different cooling rates).