KINETICS OF A S.G. CAST IRON

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Abstract

The paper presents an application for calculating the kinetics parameters in the case of a phase transformation in solid state in A.D.I. S.G. grade. It is pointed out the influence of some factors (the temperature and the holding time at the isothermal level) on the phase transformation and properties in the studied cast iron. The kinetics of austenitization of S.G. Cast Iron, was described by the "Johnson-Mehl-Avrami" equation.

Keywords: Materials Science, cast iron, heat treatment, phases transformation

Introduction

Austempered Ductile Iron (A.D.I.) with a bainitic matrix, obtained by heat treatment and isothermal hardening is the material which combines a lot of superior attributes of the classical Austempered Ductile Irons or forged iron (Batra et. al., 2003), being in a serious competition with the iron used by the moment in the automotive industry (Bahmani et. al., 1997). The combination of high strength and high toughness achieved by A.D.I. suggests the engineering use of this material will continue to expand (Simon, 1996).

A wide range of properties can be obtained in these material components owing to changes in proportions of the major phases present in the microstructure: bainitic ferrite, high carbon austenite and graphite nodules. Martensite, ferrite, iron carbides and other alloy carbides may also be present.

The paper presents an application for calculating the kinetics parameters in the case of a phase transformation in solid state in A.D.I. S.G. grade. It is pointed out the influence of some factors (the temperature and the maintained time at the isothermal level) on the phase transformation. The kinetics of austenitization of S.G. Cast Iron, was described by the Johnson-Mehl-Avrami equation.

Research objectives

This research has a number of objectives which can be started as follows:

1. Identify the effect of heat treatment over the structure and properties.
2. To determine hardness (HB) at the isothermal temperature.
3. Calculating the kinetics parameters of S. G. cast iron, using the "Johnson-Mehl-Avrami" equation.

Materials

The studied cast iron has the following chemical composition (% in weight): 3.57% C; 2.69% Si; 0.47 % Mn; 0.010%P; 0.005%S; 0.06%Mg; 0.54% Ni, 0.48%Cu. This cast iron was made in an induction furnace. Nodular changes were obtained with the "In mold" methods, with the help of prealloy FeSiCuMg. The microstructure in raw state is presented in figure 1.

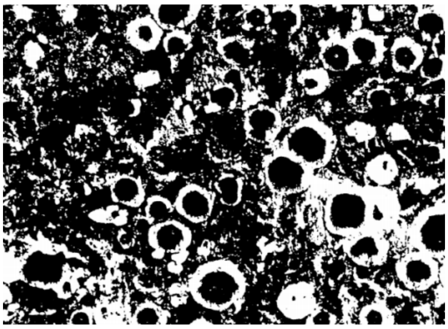

Figure 1: Microstructure in raw state (SEI at 200x magnification)

The microstructure is perlito-feritic typical for a cast iron with geometrically regular nodular form (Eric et. al., 2006).

Heat treatments

The parameters of the heat treatment done were the following: the austenizing temperature, T_A = 900 [°C]; the maintained time at austenizing temperature, τ_A = 30 [min]; the temperature at isothermal level, T_{iz} = 300 and 400 [°C]; the maintained time at the isothermal level, t_{iz} = 1; 2; 5; 10; 20; 30; 40; and 50 [min]. All these 2 experimental lots A (t_{iz} = 300° C) and B (t_{iz} = 400° C) were performed at isothermal maintenance in salt-bath, being the cooling after the isothermal maintenance was done in air.

Experimental results

From this material, 15 typical HB test specimens was done (ϕ 20 x 50 mm) and after the heat treating, it was determined the results of HB. The aim of the experiments is to determine the hardness (HB) at the isothermal temperature. The experimental values of the hardness are presented in table 1.

Table 1: The experimental values of hardness, for various T_{iz} and τ_{iz}

T_{iz} , [° C]	τ_{iz} , [min]	Hardness, [HB]		
		H_0	H_f	$H_{(t)}$
	1			488
	2			472
	5			460
	10			449
	20			435
300	30	488	402	424
	40			413
	50			402
	1			413
	2			402
	5			393
400	10	413	346	383
	20			372
	30			354
	40			346

where: H_0 – initial hardness, corresponding τ_{iz} = 1 min;

H_t – hardness obtained after a maintaining time (t) at the isothermal level, [%];

H_f – final hardness, corresponding at the maintaining time at the isothermal level, which are considered as a final time for the first stage of transformation of the bainitic reaction.

In figure 2, is presented the specific microstructure at the 200x magnification for all these 2 experimental lots A (t_{iz} = 300° C) and B (t_{iz} = 400° C) after the isothermal heat treatment.

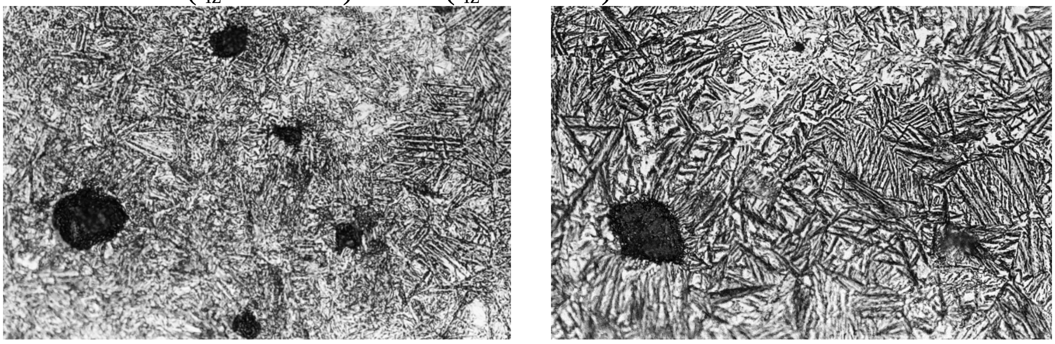

Figure 2: Microstructure: (a) lot A, τ_{iz} = 50 min; (b) lot B, τ_{iz} = 40 min (SEI at 200x magnification)

After annalizing the structure presented it was done a general observation:

- the structure of the sample maintained at t_{iz} = 300° C and τ_{iz} = 50 min, has an fine acicular form, characteristic for lower bainitic ferrite;
- the structure of the sample maintained at t_{iz} = 400° C and τ_{iz} = 40 min, has an scales form, characteristic for upper bainitic ferrite (Eric et. al., 2006).

Transformation kinetics

For the study of the phase transformation kinetics, it was used the first stage of the bainitic reaction (Liu et. al., 1995):

$$\gamma \rightarrow (\alpha) + (\gamma) \quad (1)$$

where: γ - metastable austenite;

(α) - bainitic ferrite;

(γ) - austenite enriched in carbon

In this researches work it was used the methods of the variation's hardness analyse function of the time at the isothermal level (τ_{iz}), considering that this values are depended from the proportion of the transformed fraction "$X_{(t)}$ ". It was utilised the expression:

$$X_{(t)} = \frac{H_0 - H_{(t)}}{H_0 - H_f} \text{ , [\%]} \quad (2)$$

where: $X_{(t)}$ – the transformed fraction;

H_0 – initial hardness, corresponding τ_{iz} = 1 min;

H_t – hardness obtained after a maintaining time (t) at the isothermal level, [%];

H_f – final hardness, corresponding at the maintaining time at the isothermal level which are considered as a final time for the first stage of transformation of the bainitic reaction. In figure 3 is represented the sigmoidal solid curves of the austenitic transformation during the bainite reaction.

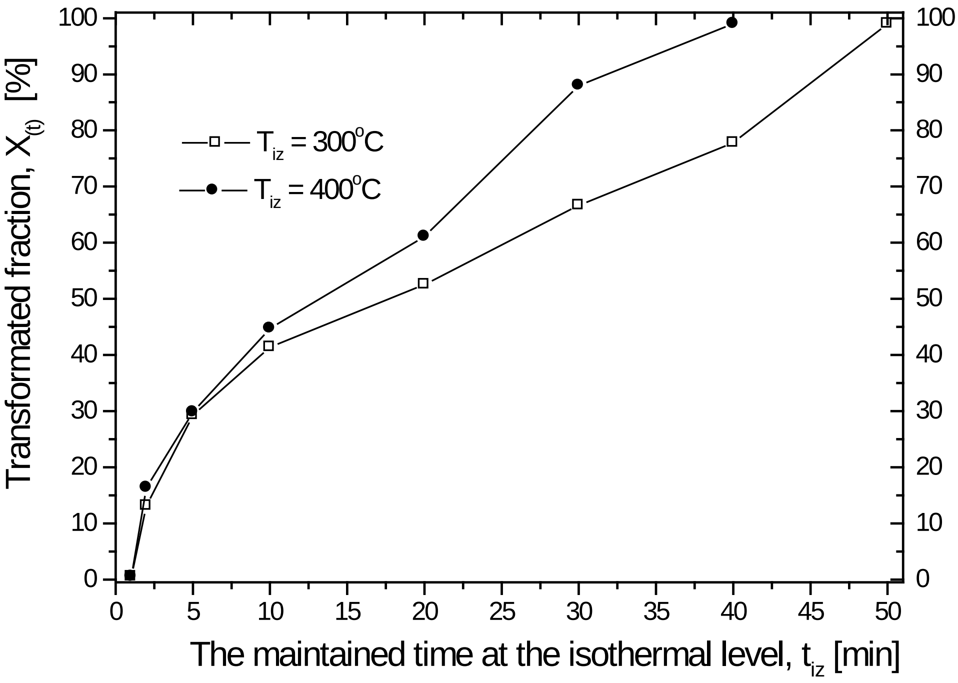

Figure 3: Transformed fraction curves at T_{iz} = 300 and 400°C, for different maintaining time

Like the transformation fraction curves have sigmoid shape, it was used the "Johnson-Mehl-Avrami" equation:

$X(t) = 1 - \exp(- k t^n)$ (3)

where: X(t) - the transformed fraction;

k - rate constant dependent on temperature;

n - exponent of the reaction.

In order to determine "k" and "n", the natural logarithmic expression was used:

$\log[-\log(1-X)] = (n \log k + \log\log e) + n \log t$ (4)

The plot of "log [-log (1-X)]"against "log t" in the isothermal temperature range 300-400°C (3, 4, 5, 6), for the isothermal maintaining time range 1 – 50 minutes, is shown in figure 4 and 5.

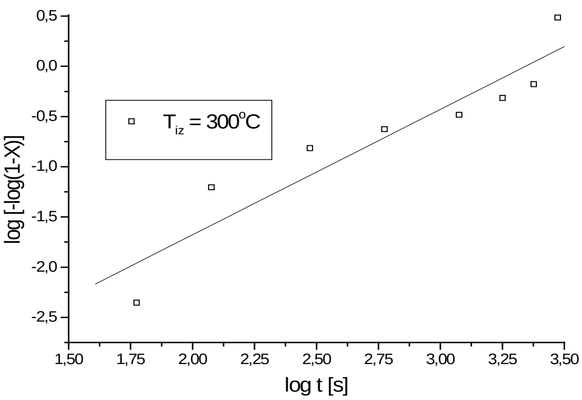

Figure 4: The plot of "log [-log(1-X)] against "logt" in the isothermal temperature 300°C.

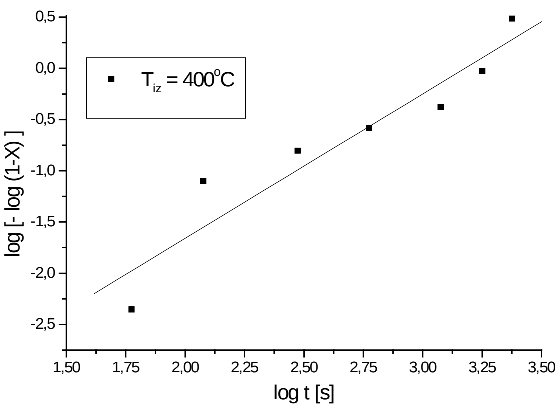

Figure 5: The plot of "log[-log(1-X)] against "logt" in the isothermal temperature 400°C.

The obtained equations from the linear regression adjustment are:

$Y_{300} = - 4.17466 + 1.1248*X$, $R^2 = 0.95$; (5)

$Y_{400} = - 4.47785 + 1.4091*X$, $R^2 = 0.95$; (6)

Values of “n” and “k” determinate from the slopes and intercepts of the linear regression lines are listed in table 2.

Table 2: *Values of “n” and “k” for the formation of bainite*

Lot	T_{iz} [°C]	n	k [1 / s]
A	300	1.25	4.574×10^{-4}
B	400	1.41	6.671×10^{-4}

According to the international researches (Liu et. al., 1995), if the “n” exponent is between 1 and 2.3 the transformation is interfacing controlled. At the same maintaining time in the isothermal level, the transformation process is different in the each maintaining isothermal temperatures (Guilemany et. al., 1990). The bainitic reaction rate "k" increases when the isothermal temperature increases from 300 to 400° C (Chou et. al., 1992).

Conclusion

The isothermal bainitic transformation in a Ni-Cu S.G. cast iron was studied in the temperature range of 300-400° C and with maintaining time between 1-50 minutes. The main results are summarized as follows:
(a) The kinetics of austenitization of S.G. cast iron, can be described by an Johnson-Mehl-Avrami equation .
(b) The reaction exponent “n”= 1.25 – 1.41 and the transformation is interface controlled.
(c) The bainitic reaction rate "k" increases with increasing isothermal temperature from 300 to 400°C.

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