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Effects of High Magnetic Field on Pearlite Transformation Behavior and Structure

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Effect of a high magnetic field of 10 T on microstructure and kinetics of pearlite transformation in Fe-13%Mn-1.0%C (mass%) steel was investigated systematically using a vacuum electric furnace installed in a superconducting magnet. It was found that a magnetic field of 10 T stimulated pearlite transformation significantly. The rates of pearlite nucleation and growth with and without magnetic field were measured. It was found that a high magnetic field increased the nucleation rate of pearlite, but hardly affects the growth rate of pearlite nodule.

Key words: high magnetic field, Fe-13Mn-1.0C, pearlite transformation, nucleation rate, grain growth rate

1. INTRODUCTION

There are many studies showing that an external magnetic field can affect martensitic transformation in ferrous alloys and steels[1-4]. However, there are few studies on the effect of a magnetic field on diffusional transformations, such as, ferrite and pearlite transformations. Recently, Oishi et al. studied the effect of magnetic field on pearlite transformation during continuous cooling in an Fe-0.82mass%C steel, and reported that a magnetic field stimulated the pearlite transformation during continuous cooling from austenitite state[5]. However the effect of a high magnetic field on isothermal pearlite transformation, especially on the nucleation and grain growth of isothermal pearlite transformation is not studied in details. The purpose of this paper is to show the effect of a high magnetic field on isothermal pearlite transformation.

2. EXPERIMENT PROCEDURE

A high manganese austenitic steel having a chemical composition of Fe-13%Mn-1.0%C (mass%) was investigated. Since this steel shows a very slow pearlite transformation process[6], the nucleation and growth of pearlite transformation in it can be measured easily. Specimens with a size of $4.5 \times 4.5 \times 0.4 mm^3$ were cut, and heat treated in a vacuum electric furnace installed in a superconducting magnet. During the heat treatment, the specimens was fixed on a ceramics holder and a thermocouple was set to get in touch with the surface of specimen in order to measure the specimen's temperature accurately. The specimens were austenitized at 1373 K for 1.8 ks in vacuum then cooled by a flow of helium gas to room temperature. Then, these specimens were annealed at 873 K for isothermal reaction with and without a magnetic field. Figure 1 shows the schematic diagram of the heat treatments. The microstructure was observed on longitudinal section of specimens by optical microscopy and scanning electron microscopy(SEM).

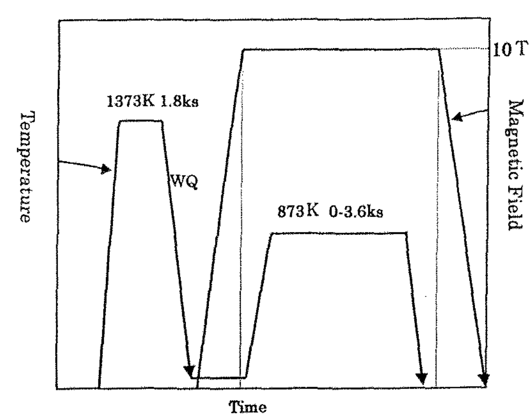

Fig. 1 Schematic diagram of heat treatments

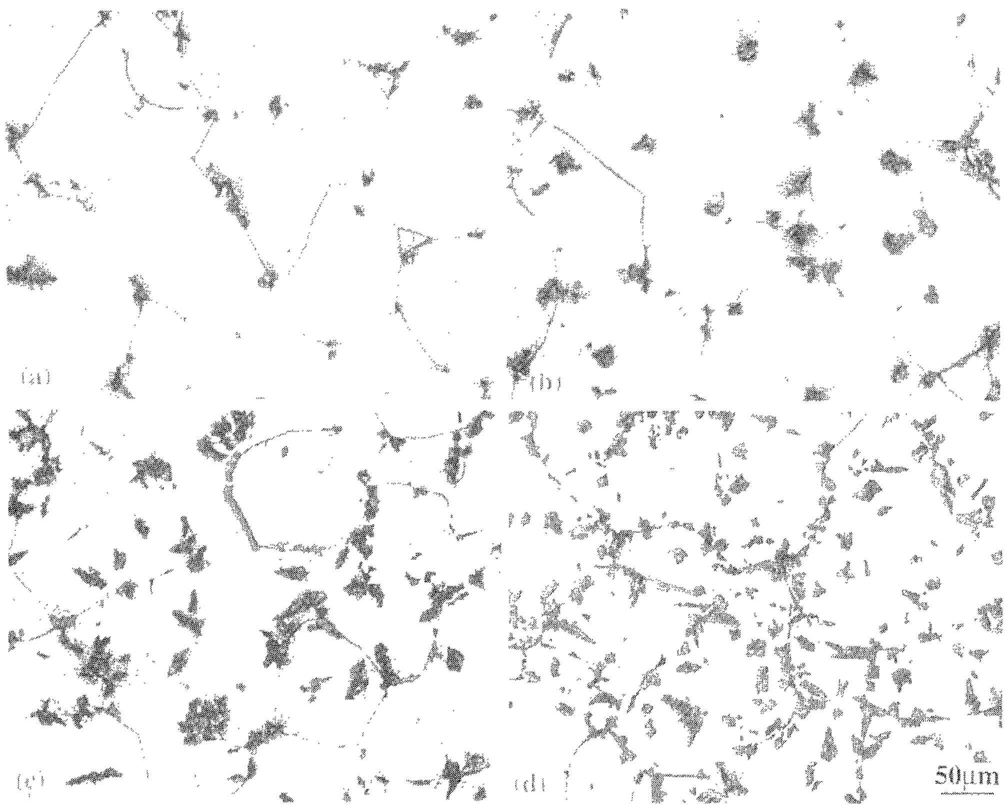

Fig. 2 Optical micrographs showing the isothermally transformed microstructure at 873 K: (a) 0 T, 1.8 ks, (b) 10 T, 1.8 ks, (c) 0 T, 3.6 ks, (d) 10 T, 3.6 ks.

The area of transformed pearlite and total number of pearlite nodules were measured carefully, and the nucleation rate was calculated. The growth rate of pearlite nodules was assessed by measuring the largest half-thickness of pearlite nodules in each specimen.

3. RESULTS AND DISCUSSION

The microstructure of the specimens austenited at 1373K for 1.8ks without magnetic field following a rapidly cooling to room temperature by a flow of helium gas was examined. A completely transformed lath martensite morphology was observed. Then these specimens were isothermally transformed at 873K with and without a magnetic field.

Figure 2 is the optical micrographs showing the structures after annealing at 873 K for 1.8ks, 3.6 ks with and without a magnetic field, respectively. The dark regions are pearlite nodules transformed during annealing. SEM observation showed that the transformed pearlite nodules had a fine lamellar eutectoid structure. Figure 3 shows the measured results of the transformed fraction during annealing with and

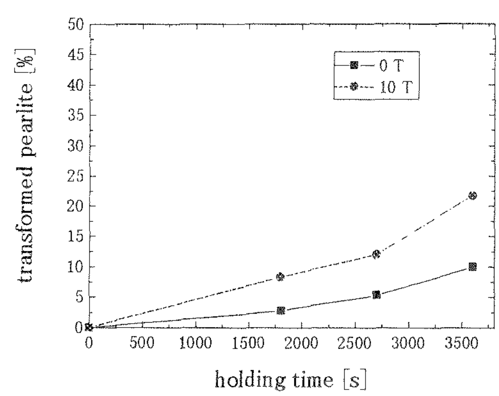

Fig. 3 Effect of a magnetic field of 10 T on the transformed fraction of pearlite at 873 K.

without a magnetic field. It was found that a magnetic field of 10 T stimulates isothermal pearlite transformation significantly.

The effect of a magnetic field on the change of Gibbs free energy was considered by Chen et al. as follows[7].

$$dG=-SdT+VdP-MdH$$

Where G is the Gibbs free energy, S is the entropy, T is the temperature, V is the volume, P is the pressure, M is the intensity of magnetization and H is the strength of the external magnetic field. As M can be expressed by the spontaneous magnetization M_f and the permeability χ as

$$M= M_f + \chi H$$

the free energy caused by an external magnetic field G_H can be expressed as

$$G_H= -M_f H-(1/2)\chi H^2$$

Thus the effect of a magnetic field on pearlite transformation can be interpreted by a thermodynamic consideration that an external magnetic field decreases Gibbs free energy then stimulates the pearlite transformation.

Figure 4 shows the effect of magnetic field on total number of pearlite nodules for specimens isothermally transformed at 873 K with and without a magnetic field. The total area for measuring the number of pearlite nodules was 0.53 mm^2 in each specimen. It was found that a magnetic field increased the total number of

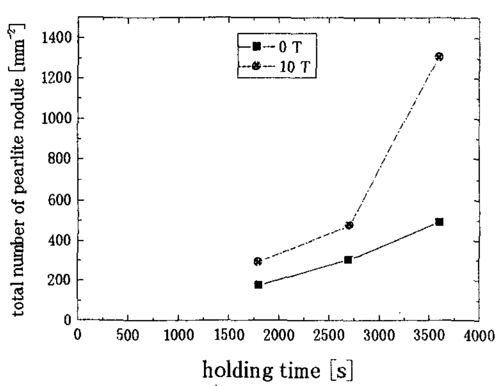

Fig. 4 Effect of a magnetic field of 10 T on the total number of pearlite nodules transformed at 873 K in Fe-13Mn-1.0C.

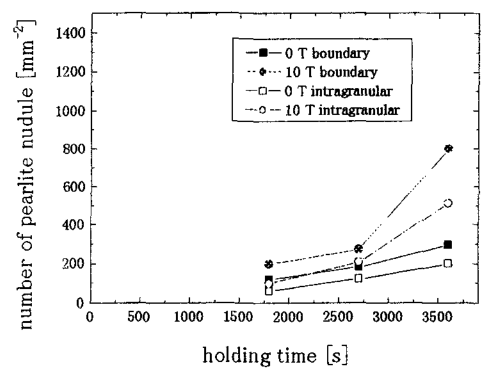

Fig. 5 Effect of a magnetic field of 10 T on the number of pearlite nodules at grain boundaries and within grains, respectively.

pearlite nodules significantly. As the pearlite nodules formed both at grain boundaries and within the grains (see Fig. 2), the effect of magnetic field on the numbers of grain boundary and intragranular pearlite nodules was also measured, respectively, as shown in Fig. 5. We see that a magnetic field stimulates the formation of pearlite both at grain boundaries and within grains.

The nucleation rate of pearlite nodules was evaluated by a method similar to the calculation of ferrite transformation[8]. Table I shows the calculation results of nucleation rate for different reaction time at 873 K with and without a magnetic field. J_v is the nucleation rate of intragranular pearlite nodules, that is, the number of pearlite nodules formed per second per unit unreacted volume. J_s is the nucleation rate of grain boundary pearlite nodules, that is, the number of pearlite nodules formed per second per unit area of unreacted grain

Table I Comparison of the nucleation rates of pearlite with and without a magnetic field for different reaction time. J_s: grain boundary nucleation rate; J_v: intragraunlar nucleation rate.

	873K,1.8ks	873K,2.7ks	873K,3.6ks
$\frac{J_{s10T}}{J_{s0T}}$	2.05	1.56	3.13
$\frac{J_{v10T}}{J_{v0T}}$	2.00	1.82	2.98

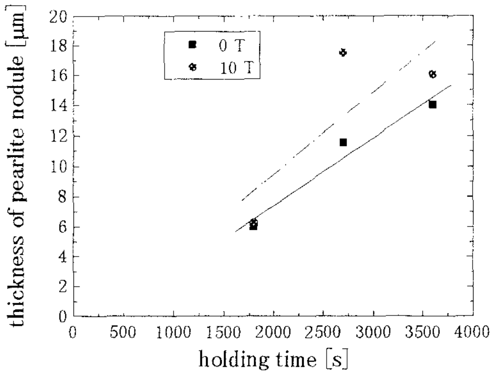

Fig. 6 Effect of magnetic field on growth rate of grain boundary pearlite nodule at 873 K in Fe-13Mn-1.0C.

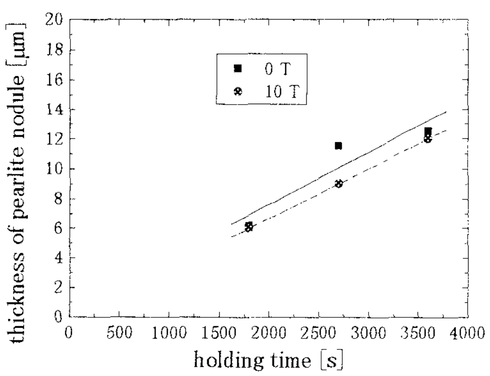

Fig. 7 Effect of magnetic field on growth rate of intragranular pearlite nodule at 873 K in Fe-13Mn-1.0C.

boundary. We see that nucleation rate of pearlite nodules increased by 1.5~3 times by a magnetic field of 10T.

The largest half-thickness as a function of the reaction time for specimens isothermally transformed with and without a magnetic field was determined, as shown in Fig. 6 for grain boundary pearlite nodule, and Fig. 7 for intragranular pearlite nodule. The growth rate was assessed from the slope of least squares lines through these plots. We see that a magnetic field hardly affects the growth rate of pearlite both at grain boundary and within grain. Since it was reported that the self-diffusion coefficient in α -iron decreases with the increase of magnetization parameter[9,10], it seems that the diffusivity of carbon may be also suppressed by a magnetic field. Thus, by considering that a magnetic field increases the transformation driving force by decreasing Gibbs free energy, but suppresses diffusivity, it can be interpreted that a magnetic field increases the nucleation rate significantly, but hardly affects the growth rate during pearlite transformation process. Further research on this is now under study.

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