JOURNAL OF MATERIALS SCIENCE **39** (2004) 1129–1130

Ferrite transformation in spheroidal graphite cast iron under a high magnetic field

WU CUN-YOU, LI TING-JU, WEN BIN, JIN JUN-ZE
Research Center of Foundry Engineering, Department of Material Science and Technology, Dalian University of Technology, Dalian 116024, LiaoNing, People's Republic of China
E-mail: watchingucn@yahoo.com.cn

With the development of super conducting materials, high magnetic fields have become easier to achieve and are being applied in various fields of science. As a result, many interesting phenomena have been found by using new experimental methods related to high magnetic fields, such as heat treatment under high magnetic field or deformation under high magnetic field. Recently, investigations were focused on the effect of high magnetic field on phase transformation behavior and microstructures. In iron-based alloys, there are many solid/solid phase transformations in which the magnetic moment of the parent phase and product phase are different, and it is expected that these transformations are affected by magnetic fields [1]. In our research, the influence of high magnetic field on the ferrite transformation was studied by means of the annealing of spheroidal graphite cast iron.

The apparatus, which can generate a maximum magnetic flux of 10.02T, has a bore size of ϕ100 mm ×460 mm inside. A water-cooling jacket made of stainless steel was inserted into the bore for keeping the bore wall at room temperature during heating of the specimen in the furnace located in the jacket. Standard tensile specimens of spheroidal graphite cast iron were prepared and annealed (kept at a temperature of about 730 °C for 3 h and then cooled to room temperature) with and without high magnetic field. Then mechanical properties of the specimens were compared. Additionally, the effect of high magnetic field on the microstructure of the specimens was investigated.

Since their as-cast structure is F+P+G (ferrite + pearlite + graphite), specimens were annealed for 3 h at a temperature of 730 °C. There is no phase transformation at this temperature because the matrix is not austenized, while the cementite and ingredient segregation can be eliminated by diffusion. Table I shows the results of the tensile experiments.

It is apparent that after imposing a high magnetic field, the tensile strength and the hardness of the specimen decreased, while the elongation and the reduction of area increased.

Comparing the SEM micrographs of the specimens with and without high magnetic field as shown in Fig. 1, where the black spots are graphite, the gray areas are ferrite and the white areas are pearlite, we found that the white areas in picture (b) are less than those in picture (a). That is to say, under high magnetic field, the pearlite disappears more quickly. We consider it is because high magnetic field accelerates the dissolution of cementite inside the pearlite.

This phenomenon is interpreted as follows. First, the specimen is magnetized during annealing under high magnetic field, and then the magnetized specimen interacts with the high magnetic field and generates a magnetization force. So the cementite flakes inside are compressed under this magnetization force, which accelerates the diffusion of the carbon from the cementite flakes. In the end it accelerates the disappearance of the pearlite. In the center of the magnetic field, the magnetization force is experienced by both parts of the specimen above and below the center. For the cementite flake at this position, which is perpendicular to the magnetic flux, we can calculate the magnetization force acting on it. For a unit volume, the magnetization force is [2]:

$$F = B_{\mathrm{s}}/\mu_0 * \frac{\partial B}{\partial z} + 1/\mu_0 * B_{\mathrm{ex}} \frac{\partial B}{\partial z} \qquad (1)$$

where F is volume force, B_{s} is saturation induction, for cast iron it is about 10 kGs, and μ_0 is space permeability.

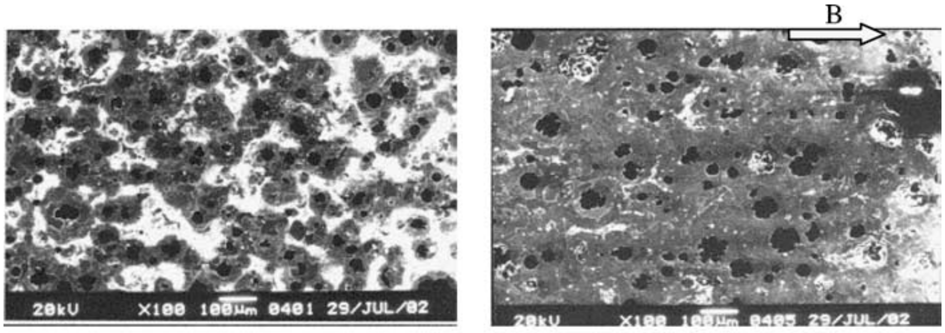
Since the thickness of the cementite flake can be ignored, the diffusion of the carbon is regarded as a kind of thin-film source diffusion. Taking the magnetization force into consideration, the solution for the diffusion equation is:

$$\ln C = \ln A + \frac{\alpha}{2}x - \frac{\alpha^2 Dt}{4} - \frac{1}{4Dt}x^2 \qquad (2)$$

where $\alpha = F/KT$ (K is Boltzmann constant, T is absolute temperature), $A = \frac{Q_0}{\sqrt{\pi Dt}}$ (D is diffusion coefficient, Q_0 is half quality of the cementite), x is the distance

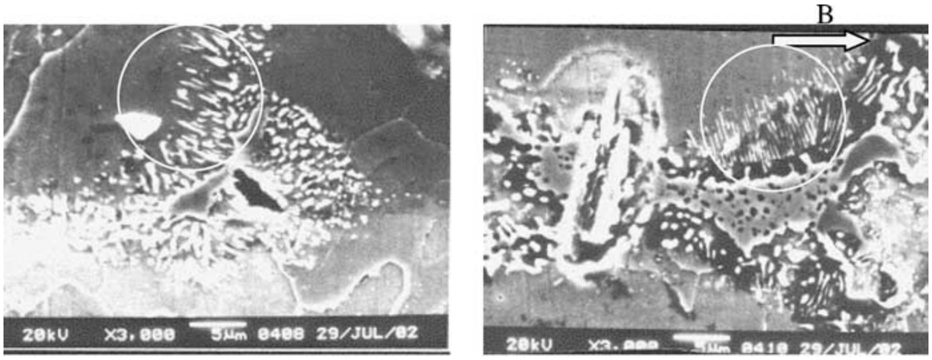
TABLE I Mechanical properties of the specimen with and without magnetic field

	Specimen status		
Mechanical properties	As-cast	Annealed ($B = 0$)	Annealed ($B = 10T$)
Tensile strength (Mpa × 10^{-3})	0.683	0.569	0.534
Elongation (%)	9.4	11.5	19.6
Reduction of area (%)	7.84	16.57	20.78
Hardness (HB)	229	207	187



(a) (b)

Figure 1 SEM micrograph of the specimen annealed at 730 °C for 10 min: (a) without magnetic field and (b) with 10T magnetic field.



(a) (b)

Figure 2 SEM micrograph of the specimen annealed at 730 °C for 180 min: (a) without magnetic field and (b) with 10T magnetic field.

between the calculated position and the cementite flake. While without magnetic field, that is $\alpha = 0$, we get:

$$\ln C = \ln A - \frac{1}{4Dt}x^2 \qquad (3)$$

At the interface between the cementite flake and the matrix, where x equals zero, the value of $\ln C$ in Equation 2 is less than that in Equation 3. That is to say, for the same treatment time, a high magnetic field accelerates the diffusion of the carbon. As shown in the circled area in Fig. 2, the white strips (namely cementite flakes) in picture (b) are much thinner and clearer than those in picture (a).

Acknowledgment

This project was supported by the National Natural Science Foundation of China (No. 50234020).

References

1. HIDEYUKI OHSUKA, YA XU, JONG-KYO CHOI, YUKIHIRO OISHI, TERUYUKI MURAI and HITOSHI WADA, The 3rd International Symposium Electromagnetic Processing of Materials, Nagoya, Japan, 2000, p. 596.
2. HIROSHI MORUKAWA, KENSUKE SASSA and SHIGEO ASAI, *Mater. Trans. JIM* (1998) 814.

Received 19 December 2002
and accepted 29 July 2003