Available online at www.sciencedirect.com
ScienceDirect

JOURNAL OF IRON AND STEEL RESEARCH, INTERNATIONAL. 2015, 22(11): 983-989

Behavior of Element Vaporization and Composition Control of Fe-Ga Alloy during Vacuum Smelting

Jian-wu YAN[1,2], Liang LUO[3], A-fang PENG[1,2], Chen-shu ZHANG[1,2], Qing-hua CAO[1,2]
(1. Jiangxi Province Key Laboratory of Precision Drive and Control, Nanchang 330099, Jiangxi, China; 2. Institute of Micro/Nano Actuation and Control, Nanchang Institute of Technology, Nanchang 330099, Jiangxi, China; 3. School of Aeronautical Manufacturing Engineering, Nanchang Hangkong University, Nanchang 330034, Jiangxi, China)

Abstract: Saturated vapor pressure, critical evaporation temperature and evaporation loss rate of Fe-Ga alloy were calculated under different conditions of Ga and Fe contents with activity coefficients. The relationship between the change of Ga content and melting time was determined. The results demonstrated that saturated vapor pressure of Ga was higher than that of Fe under the same conditions. The difference value of critical evaporation temperature of Ga with and without Ar was nearly 800 K. The critical evaporation temperature of Fe was higher than that of Ga under vacuum, indicating that Ga was more volatile than Fe. At 1 800 K, the evaporation rate of Ga was 84 times higher than that of Fe in the melt of $Fe_{81}Ga_{19}$ alloy. Under this condition, the change of Ga content and smelting time kept a linear relationship. The higher the temperature was, the faster the Ga content decreased, which was consistent with theoretical calculations.

Key words: Fe-Ga alloy; vacuum smelting; critical evaporation temperature; saturated vapor pressure; smelting time

In recent years, considerable interest has been shown in the field of magnetostrictive materials in possible benefits arising from the use of Fe-Ga alloy[1-5]. This alloy has some advantages, such as high Curie temperature, strong adaptability to temperature, low cost and so on. It also exhibits good mechanical properties (e.g., strength and ductility), which can be widely applied to navigation technology, military and security applications, target detection, geomagnetic measurements, etc.[6-10]. Its superior performance is not only attributed to alloy composition and its preparation method[11−13], but also related to its microstructure and smelting process[14-16].

However, the performance of this alloy can be changed easily by the occurrence of a small change in composition due to its low error tolerance. It has been found that alloy pollution from interstitial element in the atmosphere can be averted greatly during vacuum smelting. Ga element in Fe-Ga alloy is apt to volatilize as a result of its higher saturated vapor pressure. Under this condition, segregation of the actual alloy composition occurs, which is different from the desired composition[17]. Worse still, vacuum environment is also polluted by volatile materials. At present, few literatures on the vacuum induction smelting technology of Fe-Ga alloy are available. Proper melting processes can not only accurately control the composition of the alloy, but also effectively reduce the amount of metal waste formed, prolong the service life of equipments and decrease maintenance costs. Therefore, it appears to be of significance to explore element volatilizing characteristics and employ appropriate heating temperature and vacuum degree during vacuum smelting of the alloy[18-20].

The aim of the present work is to study volatilizing behavior of alloying element and investigate the influence of this behavior on the composition of Fe-Ga alloy melt.

1 Experimental

In the experiment, the raw material covered Fe and Ga contents with a high purity. The target $Fe_{81}Ga_{19}$ alloy was fabricated by means of quartz crucible in a vacuum induction melting furnace. The main parameters of the VIF-1 type vacuum induction furnace are presented in Table 1. The clutter inside the furnace was removed completely before experiment, ensuring that the inside of the furnace was clean and dry. Then, Ga and Fe particles were placed respectively in the quartz tube. Considering that Ga had a low melting point (29.8 °C), it was necessary to put Fe particles on the Ga particles. Finally, the quartz crucible was mounted in the induction coil.

The experiments were divided into three groups to melt using the VIF-1 type vacuum induction furnace. The temperature of melts was tested using a Marathon FA/FR1

Foundation Item: Item Sponsored by National Natural Science Foundation of China (51161019); Project of Department of Science and Technology of Jiangxi Province of China (20133BBE50011); Project of Department of Science & Technology of Jiangxi Province of China (20141BDH80025)

Biography: Jian-wu YAN, Doctor, Professor; **E-mail:** jianwuyan@163.com; **Received Date:** September 21, 2014

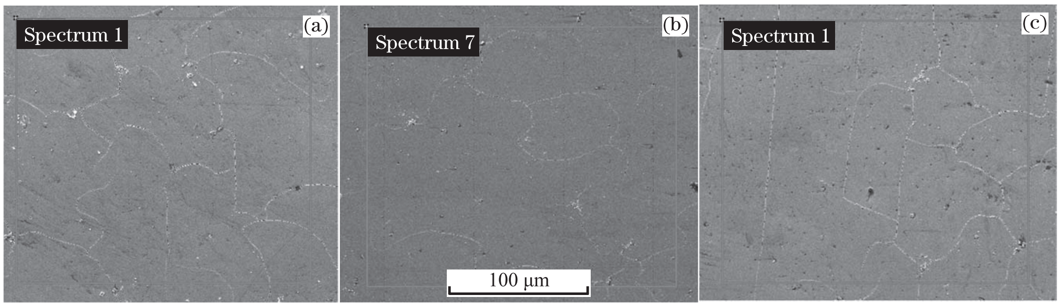
Table 1 Specifications of the VIF-1 type vacuum induction furnace

Characteristics	Typical value
Furnace profile	Horizontal furnace
Maximum smelting quantity/kg	10
Frequency/kHz	20
Maximum temperature/°C	1 200
Maximum vacuum/Pa	6.67×10^{-3}
Melting time/min	About 10

series infrared temperature measurement device. The melting temperature of tested specimens was 1 500 K, 1 600 K, and 1 700 K in turn. The control of temperature of the melt can be achieved by changing the current with a power supply voltage of 380 V. The current at 1 500 K, 1 600 K, and 1 700 K was 1 400 A, 1 440 A, and 1 470 A, respectively. After melting Fe-Ga alloy, molten metal was poured into a die with diameter of 10 mm and length of 120 mm, and then its components were tested. The mass of the alloy before and after smelting was measured employing a BSA-8201-CW type electronic balance. The element distribution and average compositions of Fe-Ga alloy were analyzed using an energy dispersive spectroscope (EDS) and a scanning electron microscope (SEM). Area scanning in different zones was used to characterize the composition of Fe-Ga alloy under different conditions. The composition of Fe-Ga alloy in the experiment was measured repeatedly and the average was taken to greatly reduce the error. The data of mass and compositions of the alloy at different time were tested so as to compare with results from theoretical calculations.

2 Results

Fig. 1 shows the microstructure and compositions of Fe-Ga alloy cast at 1 600 K for different melting time.



(a)

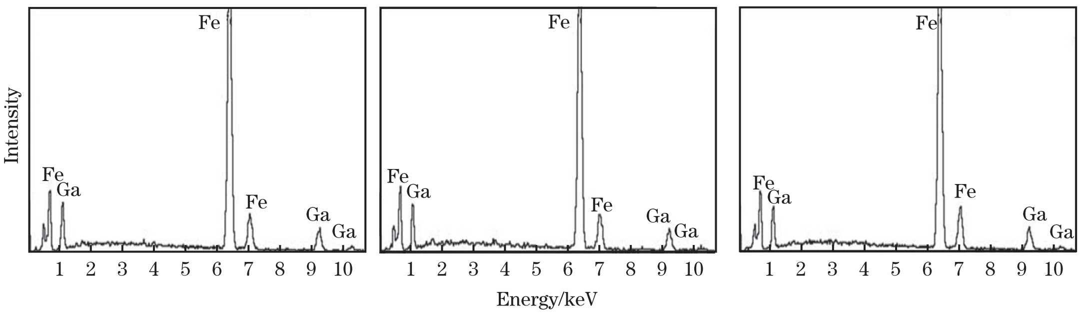
Element	mass%	at.%
Fe	78.51	82.04
Ga	21.49	17.96
Total	100.00	

(b)

Element	mass%	at.%
Fe	79.02	82.48
Ga	20.98	17.52
Total	100.00	

(c)

Element	mass%	at.%
Fe	79.02	82.48
Ga	20.98	17.52
Total	100.00	



(a) 10 s; (b) 15 s (c) 20 s.

Fig. 1 Microstructure and compositions of Fe-Ga alloy cast at 1 600 K for different evaporation time

It can be observed that Ga content decreased gradually while Fe content increased continually with prolonging melting time. It can also be noticed that grains with an irregular shape in Fe-Ga alloy became relatively coarse and there were a small amount of white dotted precipitates in the grain boundary. As the Ga content reduced, the precipitates also gradually decreased, which demonstrated that the precipitates were closely related to the composition of Fe-Ga alloy. Based on the aforementioned experimental results, the relationship of Ga content and its smelting volatilization time in Fe-Ga alloy is displayed in Fig. 2.

Fig. 3 reveals the EDS results of small amounts of residual metal at the pouring gate with a melting temperature of 1 600 K and evaporation time of 20 s. As shown in Fig. 3, a certain proportion of oxygen element