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EFFECT OF ALUMINUM ON STABILITY OF RETAINED AUSTENITE IN BAINITIC MALLEABLE CAST IRON

A. R. Kiani-Rashid[1]

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The effect of aluminum additives on the microstructure of bainitic malleable cast iron after heat treatment consisting of isothermal hardening at 350°C in a bath with molten lead after a hold at 920°C for 90 min is studied. A metallographic study is performed by the methods of light and scanning electron microscopy and x-ray diffraction analysis of the metal.

Key words: cast iron, heat treatment, microstructure, metallography.

INTRODUCTION

The bainite structure formed in bainitic malleable cast iron with high concentration of silicon is commonly characterized by high content of retained austenite supersaturated with carbon, because the formation of cementite in isothermal hardening of cast iron is suppressed by the presence of silicon [1 – 3]. The final microstructure determining the mechanical properties of cast iron depends on the temperature and time conditions of the austenization and of the isothermal hold. The austenite transforms into plates of upper bainite and carbon-enriched retained austenite at elevated temperatures of isothermal hold or into nonplastic ferrite-carbide aggregates of lower bainite at a lower temperature [4]. High-carbon retained austenite has also been detected in formation of lower bainite. When the high-carbon retained austenite decomposes, a carbide may segregate between plates of bainitic ferrite.

It is known that by changing the chemical composition and the mode of heat treatment of bainitic cast iron we can change their properties and obtain various combinations of strength, hardness, impact toughness, and wear resistance. The range of application of such iron can be widened by varying the content of silicon and its partial replacement by aluminum [5 – 8]. The effect of substitution of silicon by aluminum on the bainitic microstructure of cast iron has not been studied in detail. The authors of [9] have observed a change in the proportion of ferrite to retained austenite due to changing the mode of heat treatment of not alloyed bainitic cast iron with globular graphite. They have shown that in the final stage of the isothermal transformation high-carbon retained austenite decomposes into ferrite and carbides so that the final microstructure of the iron contains ferrite, retained austenite, and carbide segregations. It is assumed in some works that the bainitic microstructure in cast iron is characterized by supersaturation of carbon (removed from bainitic ferrite), which is enough for stabilization of the austenite up to a temperature lower than room one [10 – 13]. The effect of the mode of austenization and isothermal hardening on the microstructure of cast iron with globular graphite containing 2.25% Al is studied in [13, 14]. It is shown that the temperature of the isothermal hold determines the morphology of bainite and the volume fraction of retained austenite in cast iron. The temperature of the austenization and the duration of the isothermal hold affect the structure of the metal but weakly.

The aim of the present work consisted in studying the effect of aluminum on the microstructure of bainitic cast iron after isothermal hardening.

METHODS OF STUDY

The experimental malleable irons (see Table 1) were melted in an open gas furnace with a capacity of 25 kg and in a high-frequency furnace with a capacity of 20 kg. The melt was superheated to 1550°C. Lumped aluminum was introduced under the heel (onto the bottom of the crucible). In order to dissolve the aluminum, the melt was held for different times. Then the melt was enriched with an iron-silicon hardener containing 5% Mg. To prevent splashing of the liquid metal during the dissolution of magnesium, the hardener was placed preliminarily into closed capsules. Then we intro-

[1] Ferdowsi University of Mashhad, Iran (e-mail: fkiana@yahoo.com; kianirashid@gmail.com).

TABLE 1. Chemical Composition of Cast Iron

Alloy	Content of elements (wt.%)							
	C	Al	Si	Ni	Mn	P	S	Mg
1	3.68	0.48	1.06	0.04	0.06	< 0.005	< 0.005	0.05
2	3.44	4.88	1.22	0.05	0.10	< 0.005	< 0.005	0.05

duced a ferrosilicon inoculant containing 75% Si into the crucible with the melt. Each heat was treated by the sandwich method at 1400°C with ferrosilicon bearing 5% Mg. The metal was cast into sand molds at 1330°C. The carbon content was determined using the equipment of the Swinden Technology Center of the Corus Group PLC by the method of absorption in the infrared spectrum range after firing the sample in an induction furnace and oxidation of carbon to CO_2. The content of aluminum was evaluated by the method of atomic absorption spectrophotometry in the Hi-Search Technology (HIST) laboratory of the Birmingham University. For all the chosen compositions the content of nodular graphite exceeded 90%. The structure of the metal was studied using light and scanning electron microscopy and a Nikon D.I.C. polarizing interference microscope and a Reichert-Jung microscope. Scanning electron microscopy was performed using Cambridge Series 3 SEM microscopes with an attachment for energy dispersive chemical analysis (Link 860 series 1 EDX) and Cambridge Series 4 SEM. The accelerating voltage was 20 kV; the diameter of the electron probe was 4 – 6 nm.

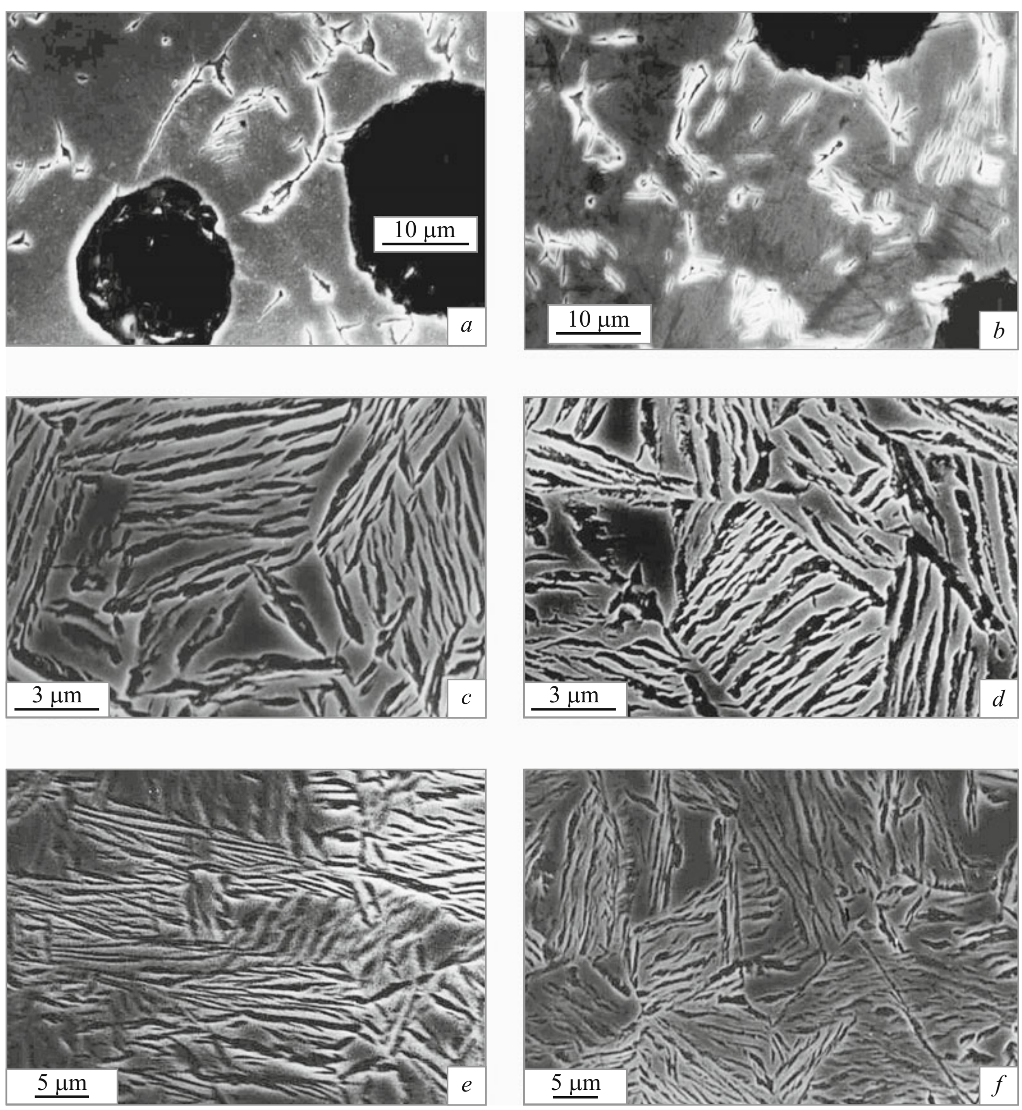

Fig. 1. Microstructure of aluminum-alloyed bainitic malleable irons (scanning electron microscopy) after austenization at 920°C for 90 min and isothermal hardening at 350°C for 1 min (*a*, *b*), 100 min (*c*, *d*), and 16 days (*e*, *f*): *a*, *c*, *e*) 0.48% aluminum in the metal; *b*, *d*, *f*) 4.88% Al.

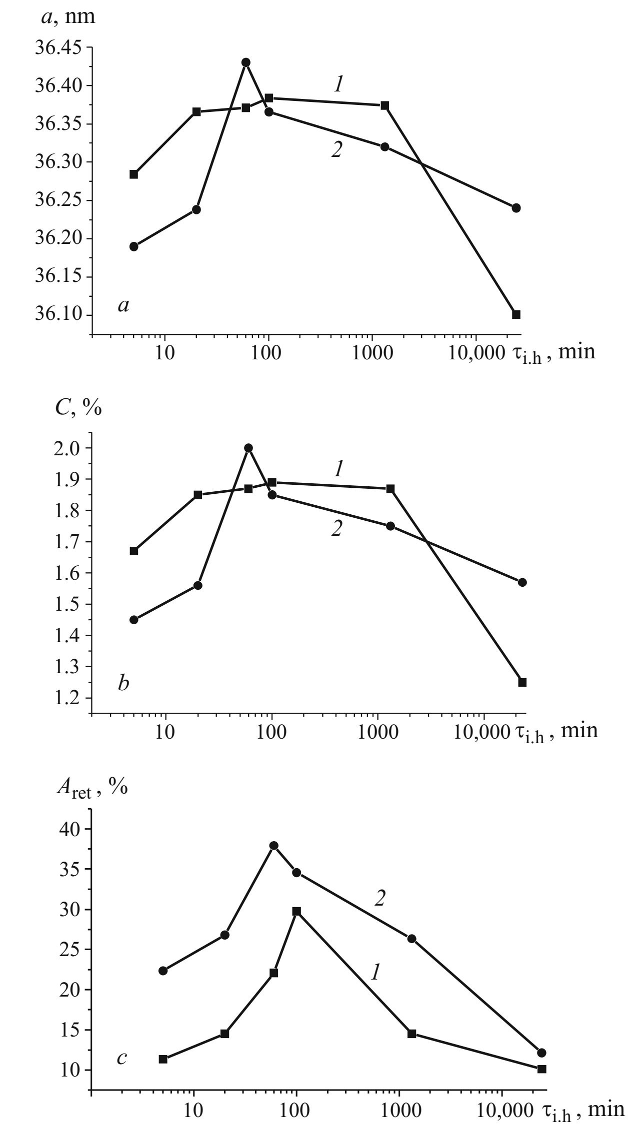

Fig. 2. Dependence of the lattice parameter of austenite (*a*), the content of carbon in the austenite (*b*), and content of retained austenite (*c*) on the time of isothermal hold of cast irons with different contents of aluminum: *1*) 0.48% Al; *2*) 4.88% Al.

The specimens were subjected to austenization at 920°C for 90 min, after which they were transferred into a pool of molten lead with a temperature of 350°C and held there for different times (up to 16 days). The volume fraction of austenite was determined using a Philips ADP 1700 x-ray diffractometer in copper K_α radiation. The surface to be studied was preliminarily ground against an abrasive paper and polished with diamond paste.

RESULTS AND DISCUSSION

The results of the studies of microstructure and of the x-ray study are presented in Figs. 1 and 2. After a short-term isothermal hold the matrix consists of alternating laths of bainitic ferrite and high-carbon retained austenite. We can also see equiaxed regions of retained austenite and martensite. The content of martensite decreases upon growth in the duration of the hold. When the hold is long, retained austenite may transform into a ferrite-carbide mixture [7]. These results agree with the data of many works, for example of [3], where the matrix of malleable cast iron with 2.3% Si after isothermal hardening consisted of thin laths of bainitic ferrite, retained austenite and martensite at short holds. During the hold the content of martensite decreased, the content of carbon in the austenite increased, and the carbide phase was represented by cementite. In [19] the cast iron containing manganese, molybdenum and nickel contained composite carbides after a hold at 410°C. After a hold at 300 and 370°C the structure of the metal contained no carbide and was represented only by bainitic ferrite and austenite.

We also determined the content of bainitic ferrite after isothermal transformation at 350°C. A longer hold of cast iron with high content of aluminum resulted in formation of an elevated content of bainitic ferrite, which agrees with the data of [1].

Scanning microscopy (Fig. 1*a* and *b*) shows that the microstructure of the metals with 0.48 and 4.88% Al after an isothermal hold at 350°C for 1 min consists of bainitic ferrite and martensite. The bainitic reaction has not developed fully, and the austenite retained after the hold has transformed into martensite due to water hardening. After a hold for 100 min at 350°C the structure of these metals contained plates of bainitic ferrite and a high proportion of retained austenite (Fig. 1*c* and *d*). As compared to the structure presented in Fig. 1*a* and *b* we can see growth in the proportion of bainitic ferrite. The apparently lower degree of bainitic transformation in the metal with 0.48% Al may be a result of a larger size of grains of the initial austenite as compared to the metal with 4.88% Al. After a hold for 16 days (384 h) retained austenite is still present in the structure (Fig. 1*e* and *f*). According to the data of [2], cast iron with globular graphite contains retained austenite after a 200-h hold at 350°C. The results presented in Fig. 1*c* and *d* show that when the content of aluminum is increased, the proportion of retained austenite with equiaxed morphology decreases.

The concentration of carbon in the austenite was determined in terms of its lattice constant (Fig. 2*a*). Figure 2*b* reflects the effect of the duration of isothermal hold on the content of carbon in retained austenite. Figure 2*c* presents the dependence of the volume fraction of retained austenite on the duration of isothermal hold. The behavior of the proportion of retained austenite during a hold matches the conventional concept of bainitic transformation, i.e., the austenite is first stabilized due to the growth in the content of carbon in it (which leaves the ferrite) and then decomposes into ferrite and carbide after 100 min of holding [3, 12, 15]. The curves for both metals (with low and high contents of aluminum) are similar; the elevated content of retained austenite at the higher content of aluminum agrees with the data of [1]. Taking into account the data of Fig. 2*c* we may state that the bainitic transformation develops more rapidly in the cast iron with the higher content of aluminum.

CONCLUSIONS

1. The microstructure of bainitic malleable cast iron with an additive of 0.48 and 4.88% of aluminum after hardening from 920°C (90 min) with an isothermal hold at 350°C and subsequent cooling in water is typical for bainitic transformation and consists of alternating laths of bainitic ferrite and high-carbon retained austenite.

2. The content of retained austenite in the process of isothermal hold at 350°C increases for up to 100 min and then decreases smoothly. Growth in the hold time is also accompanied by decrease in the content of martensite.

3. When the content of aluminum in the metal is increased, the proportion of retained austenite with equiaxed morphology decreases as compared to the austenite with lamellar morphology.

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