Cryogen and heat treatments of boron-lacquered high-strength cast iron

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Abstract

   This work studied the effectiveness of the interrupted isothermal quenching and subsequent cryogenic treatment, as well as direct hardening options for the purpose of varying the structure and hardening of high-strength cast iron with boron microalloy,. The paper focused on deeply refined high-strength cast iron with sulfur content less than 0.002%, along with the influence of thermal and cryogenic treatment on the evolution of the phase composition of the cast irons. To obtain a different structure in the metal matrix, four groups of samples were prepared, and were subjected to different duration of austenitization (60, 90, 150 and 210 min.) at 950°C. The process of formation of the bainite phase was carried out at 400°C and interrupted at controlled intervals of 7, 15, 30, 45, 60 and 75 minutes. The samples were then hardened in liquid nitrogen.
   A set of the experimental cast irons was subjected to direct hardening. Samples for austenization of the structure were kept at a temperature of 950°C for 60, 90, 150 and 210 minutes, then hardened in water or liquid nitrogen.
   It has been established that the hardening of high-strength cast iron with boron microalloy is an effective method of hardening the metal matrix. The combination of isothermal hardening and cryogenic processing methods allows for a wide range of structural combinations of bainite and martensitic phases to be purposefully formed in boron microalloyed high-strength cast irons, as a function of exploitation and operation conditions.

Keywords: ADI, martensite, retained austenite, isothermal quenching, cryogenic processing.

1. Introduction

   Referring to the studies in [1-5], bainite cast iron remains one of the most promising material for the manufacture of structural elements for modern brake systems of automobile and high-speed railway transport. Its excellent mechanical characteristics allows increasing loads in the contact zone and the wear resistance of frictional surfaces.

   The functional properties of bainite cast iron are largely determined by the structure of the metal matrix [6-9], which can be induced by heat treatment. Depending on the modes of heat treatment, the resulting material is a mix phases of bainite of various types and residual austenite. It should be noted that the mechanical indicators of these phase-components (upper-, lower bainite, residual austenite) differ significantly, along with their ratio. This gives a wide range for modification and manipulation of functional characteristics. At the same time, an effective use of bainite cast iron in friction conditions, can be ensured only with an optimal ratio of structural constituents.

   Some theoretical studies [10-12] aimed at synthesizing multiphase structures containing certain amounts of martensite in high-strength cast iron, which, is characterized by higher hardness and wear resistance. The complexity of the problem is due to the fact that the martensitic transformation is of a shear nature, accompanied by an increase in volume and this leads to significant internal stresses. The latter causes microcracks formation in the cast iron hardening process. In addition, The Ni, Mo and Cu, which are part of bainite cast iron, reduce the temperature of the beginning of martensitic transformation [13]. Consequently, the effectiveness of martensitic hardening of residual austenite during quenching in water is not sufficient enough.

   The frictional properties of high-strength cast iron can be significantly improved due to the formation of strengthening phases in the structure of the metal matrix [1 4-1 6]. It has been shown that alloying of high-strength cast irons with V, W, Mo, and B induces the formation of dispersed nitrides, carbonitrides and intermetallic matter in the metal matrix. These dispersions are located along the grain boundaries, strengthen them and reduce the diffusion permeability[1 7,1 8].

   Therefore, it is possible to notice the high-strength bainite cast iron due boron microalloy [19], which do not contain expensive and scarce metal as Ni, Mo and Cu. Microalloying of high-strength cast iron with 0.03% boron increases the diffusion activity of carbon and reduces the duration of isothermal quenching. The dispersion of the structure and the level of frictional characteristics increase. At the same time, the range of variation in the structural-phase composition and operational properties of high-strength cast irons is expanded due to a change in the modes of their thermal processing. According to the data presented in the work [20], cauldron alloys are characterized by high plasticity at temperatures of 850-950°C, and therefore are of interest from the point of view of the possibility of

strengthening their metal matrix with different variants of bainite-martensitic structures.

This work studies, the influence of methods of thermal and cryogenic treatment on the structure and hardness of high-strength cast iron microalloyed with boron.

2. Experimental work and Results

The object of this study is the high-strength cast iron microalloyed with boron, and, its chemical composition is presented in Table 1. To ensure high crack-resistance, the concentration of silicon in the alloy was maintained at 2.1-2.2%, and the sulfur content was 0.002%. For this purpose, the cast iron melt was subjected to deep refining, taking into account the thermodynamics of the process at temperatures of 1320-1340°C, with magnesium metal vapors using a specially developed technology. Smelting of raw materials was carried out in a laboratory induction furnace with a crucible capacity of 40 kg. When smelting cast iron, 90% of cast iron and 10% of steel scrap were used. For microalloying, a ferro-boron with 17% boron was used. The liquid metal was first modified with magnesium metal vapors for 5 minutes, and then, after holding to 1480-1500 ° C, boron microalloying was performed. Liquid metal after inoculated modification was poured into pre-prepared casting molds at 1420 ° C.

Table 1. Chemical composition of experimented ductile irons (wt, %)

Alloy	C	Si	Mn	S	B	Mg	P
A-1	3,53	2,15	0,32	<0,002	0,03	0,041	0,040

To study the features of the formed structures, pre-prepared cylindrical samples were subjected to various methods of direct and isothermal hardening. Austenitization was carried out at a temperature of 950 ° C, and isothermal hardening at 400 ° C.

The time of austenitization before direct and isothermal hardening was: 90; 150; 210 and 240 minutes and the duration of isothermal hardening was 7; 15; 30; 60 minutes. Water, melt Pb and Sb and liquid nitrogen at -196.7C were used as quenching medium.

The structure of the metal matrix after respective treatments was studied at various magnifications on the metallographic microscale Neophot 32. To identify the structure, the specimen were ground and polished then treated with a 3% alcohol solution of nitric acid.

The ratio of structural components of bainite-martensitic in the high-strength cast irons was established with X-Ray diffraction technique on the DRON-4 diffractometer using CoKα radiation. The hardness of the experimental samples was measured at Rockwell scale.

3. 3. Results and Discussions

The experimental procedures took into account the size of the initial austenitic grain. The degree of its saturation with carbon, and its carbon concentration were a function of the temperature and duration of austenitization and which significantly affects the kinetics of the processes of structure formation during isothermal quenching (isothermal quenching, austempering), the morphology and ratio of phase components of high-strength cast iron. The experimental samples of the first stage were subjected to heat treatment according to the modes schematically represented in Fig. 1. When choosing the heat treatment regime, it was taken into account that with isothermal quenching (austempering- e), the concentration of carbon in residual austenite continuously increases. This causes its stabilization and, ultimately, the process of formation of bainite stops. An increase in the carbon content in residual austenite leads to a decrease in the temperature of the beginning of martensitic transformation and prevents the possibility of hardening the metal matrix by quenching in water.
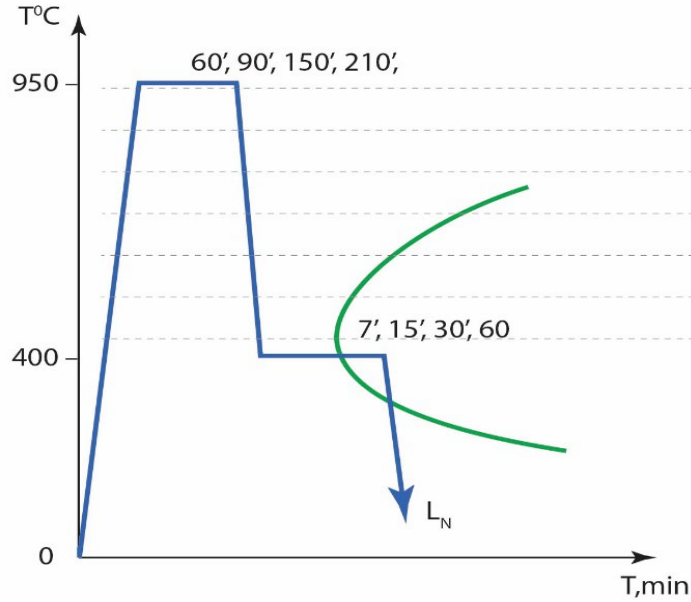
Fig.1 Austempering heat-treatment conditions.

To obtain different structures in the metal matrix, four groups of samples were prepared, each of which was subjected to different duration of austenitization (60, 9 0, 150 and 210 min.) at 950 ° C, and the process of formation of the bainite phase at 400 ° C was interrupted at controlled intervals - 7, 15, 30, 45, 60 and 75 min. They differed in the volume of unconverted residual austenite and the amount of dissolved carbon. The analysis of the data showed that the austenitization time significantly affects the amount of residual austenite and the hardness of the metal matrix at an equal duration of isothermal quenching (Fig. 2). Increasing the holding time of samples at 950 ° C contributes to the saturation of the original austenite with carbon. This increases its stability during subsequent isothermal quenching in the region of intermediate temperatures - in this case, 400°C. however, with the increase in carbon content, the degree of decay of the original austenite at $\gamma - \alpha$ transformation drops and the amount of residual austenite in the final structure of the metal matrix reaches 28 - 35%.
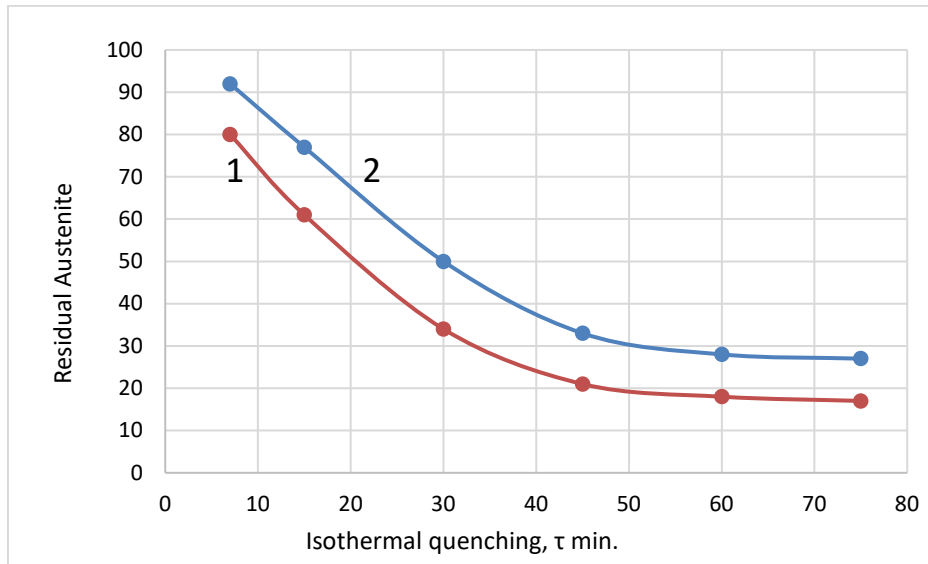

Fig.2 Effect of isothermal hardening time on the content of residual austenite in the structure;
1 – austenitization time 150 min. ; 2 – austenitization time 210 min.
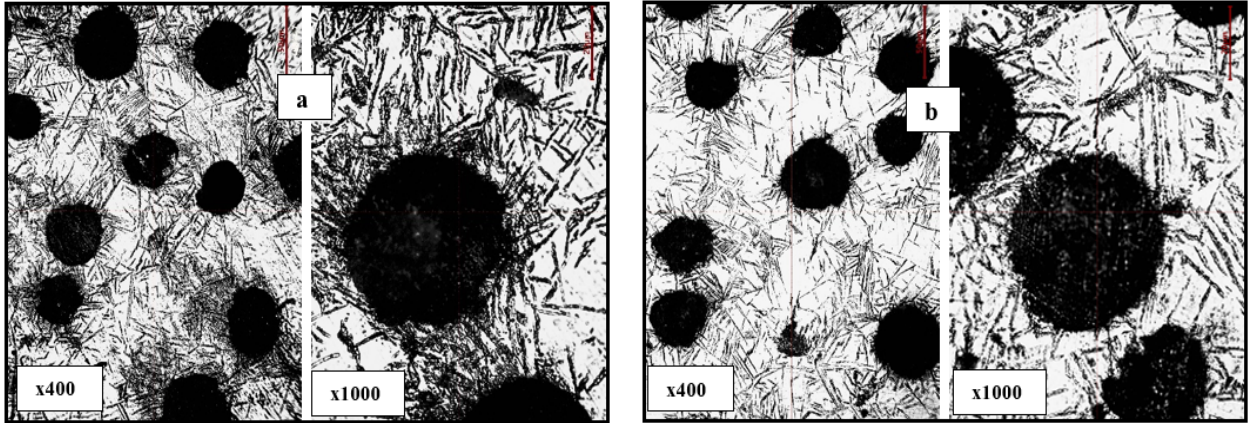
Fig. 3 The microstructures of ductile iron, austempered at 400°C / 15 min. after austenitized at 950°C -150 min.   (a) and 210 min. (b)

Fig. 3 shows a typical microstructure of boron-microalloyed high-strength cast irons. Here one can see in the microstructures that, an increase in the austenitization time helps to increase the stability of the original austenite and with the same austempering time in the structure of the metal matrix there is a greater the amount of residual austenite. As a result of targeted interruption of bainite transformation, the volume fraction of residual austenite in experimental samples can be in the range of 60-78%," which causes a low hardness of the metal matrix - 19 - 24 HRC.

It is possible to maintain a controlled amount of thermodynamically unstable residual austenite in the structure of experimental samples. Consequently, it is possible to strengthen the matrix of high-strength cast iron by further hardening to martensite. To ensure a completeness of the martensitic transformation, the samples were harden in liquid nitrogen.   Fig.4 illustrates the microstructure of high-strength cast iron after stepwise processing regime of austenitization : - incomplete isothermal hardening - quenching in liquid nitrogen.
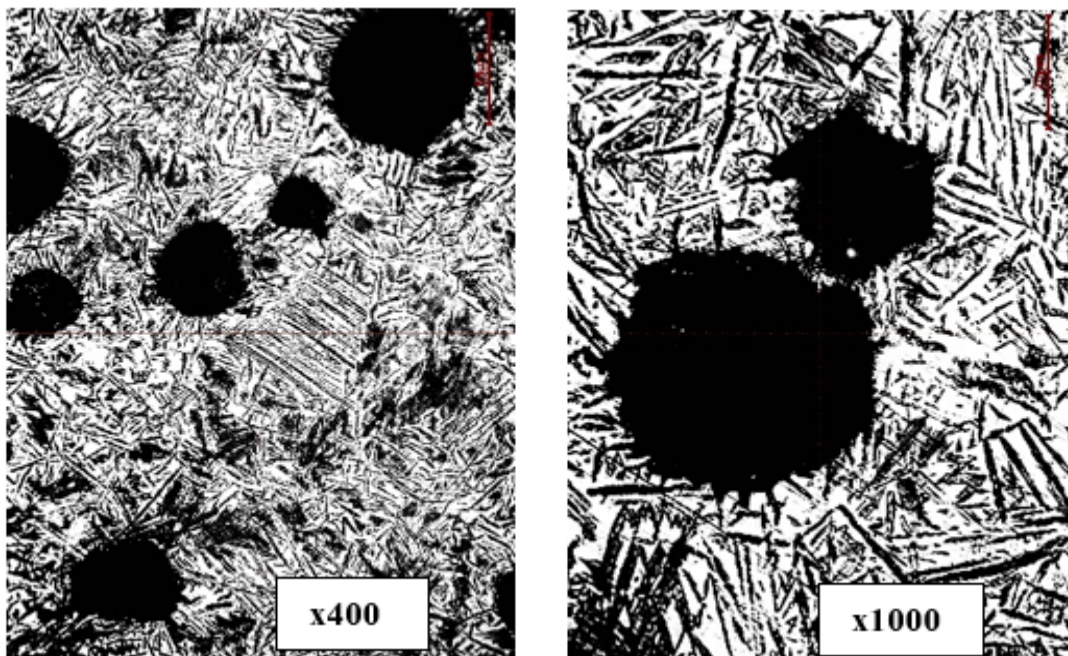

Fig. 4 The microstructures of ductile iron, austempered at 400°C / 15 min. and quenched in liquid nitrogen after austenitized at 950°C -150 min.

Hardening high-strength cast iron with boron microalloy causes the transformation of supercooled and unstable residual austenite into martensite, the crystals of which are distributed throughout the volume of the metal matrix. At the same time, in the polished plane, evenly distributed areas of residual austenite are observed, the volume fraction of which depends on the abundance and stability of the non-converted (not transformed) residual austenite during austempering. Depending on the formed martensitic phase, the hardness of the bainite-martensitic high-strength cast iron increases, which can increase after quenching in liquid nitrogen, along with a direct relation with the ratio of

structural components by 1.8-2 times (see Fig. 5). The results show that the duration of the austenization and isothermal hardening allows obtaining after cryogenic processing, a wide range of structural combinations of bainite-martensite with counteracted content of residual austenite. It was found that high-carbon austenite (~1.05 % C) is high stable and practically does not disintegrate with the formation of bainite or martensite. Therefore the effectiveness of strengthening such cast irons with cryogenic treatment decreases. In the polished and etched plane after quenching in liquid nitrogen, no hardening microcracks are observed, which indicates a high cracking-resistance of boron-microalloyed cast iron with a low sulfur content.??
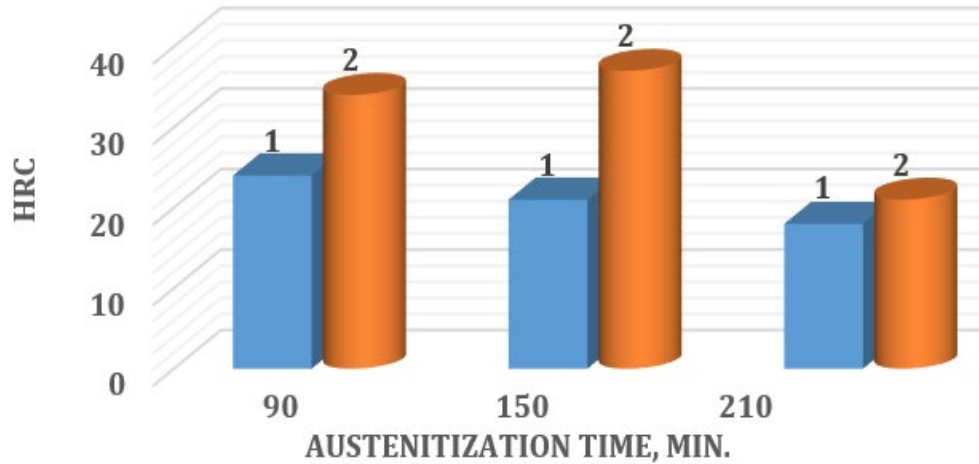

Fig.5 Effect of austenitization time on the hardness of bainite (1) and bainite-martensitic (2) high-strength cast iron

The experimental cast irons were also subjected to direct hardening. Samples for austenization structure were kept at a temperature of 950°C for 60, 90, 150 and 210 minutes, then hardened in water or in liquid nitrogen. A typical microstructure of hardened samples with a martensitic-austenitic matrix is presented in Fig. 6. Here it is observed that, direct hardening does not microcracks. The metal matrix hardened in liquid nitrogen has a more dispersed structure. However, for the give time the austenitization around graphite inclusions, some residual austenite are observed.
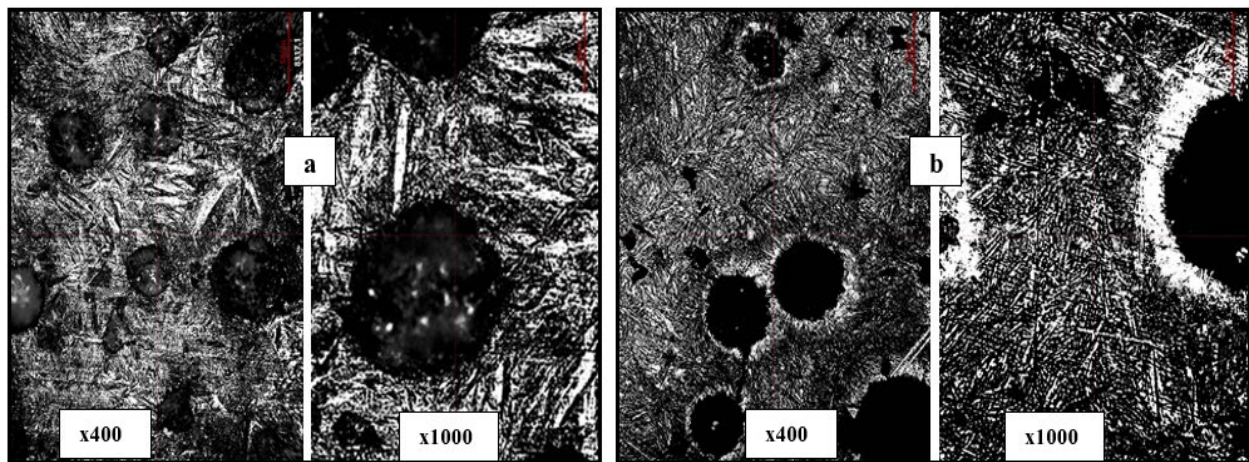

Fig.6 The microstructures of ductile iron austenitized at 950°C - 60 min. and quenched in water (a) and liquid nitrogen (b);
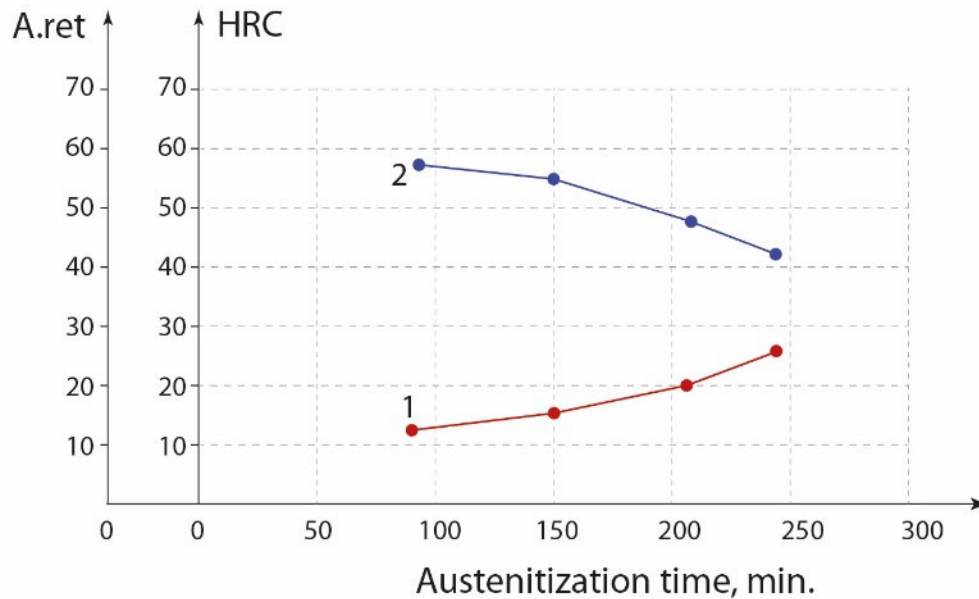
Fig. 7 Effect of austenitization time on the amount of residual austenite (1) and hardness (2) of boron-microalloyed martensitic high-strength cast irons.

Depending on the duration of austenitization in the final structure, it is possible to induce different amounts of residual austenite, which affects the hardness of the metal matrix. This is illustrated in Fig. 7, and, by doing so one can influence the functional characteristics of the material as a whole. Thus, it can be concluded that the combination of interrupted isothermal hardening and cryogenic processing allows to form a multiphase structure in cast iron microalloyed with boron and differentiate their functional characteristics.

4. Conclusion

The analysis of the experimental data leads to the following conclusion :
- The use of interrupted isothermal hardening and cryogenic processing allows engineering a wide range of structural combinations of bainite and martensitic phases to be purposely induced in boron microalloyed high-strength cast irons, as a function of planned operating conditions
- Boron-microalloyed high-strength cast iron with less than 0.003 % S are characterized by high crack resistance.
- Direct hardening of high-strength cast iron microalloyed with boron is an effective method of hardening the metal matrix
- Cryogenic treatment of the cast iron samples secured a complete conversion of supercooled austenite into martensite
- The time given for austenitization during direct hardening and combined heat treatment of boron-microalloyed high-strength cast irons significantly affects the morphology and the ratio of structural constituents

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