An Effective Way of Obtaining Bainite Structure in Alloyed High-Strength Cast Irons

R.K. Hasanli$^{1,a}$

$^1$— Associated professor, Dr., Azerbaijan Technical University, Baku, Azerbaijan

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**Keywords:** high-strength cast iron, globular graphite, economical alloying, mold, heat treatment, isothermal transformations, the details of locking devices, structure, properties.

**ABSTRACT.** This paper describes the features of the isothermal transformation in high-strength nodular cast iron. It explores the feasibility and effectiveness of obtaining bainite structure in the cast iron economically-alloyed with Nickel, copper and molybdenum cast in metallic form by continuous cooling air.

**Introduction.** In the coming years, the engineering industry of Azerbaijan should significantly be improved by the quality of the products. The most effective way to solve this problem is development of advanced structural materials, used for manufacturing various parts used in Oil and Gas industry machinery.

The use of high-strength cast iron with nodular graphite (ductile iron) instead of alloy steel for producing machine parts is a promising direction of materials science development in mechanical engineering.

In accordance with existing manufacturing technology, critical parts of the locking devices of oilfield equipment are produced from alloyed steels and subjected to bulk quenching or normalizing, followed by nitrating to provide high wear resistance and toughness.

**Analyses of the Bainite Structure of High-Strength Cast Irons.** For ductile iron, such processing is unsuitable, as parts made from cast iron with volumetric hardening are prone to cracks. Nitrating ductile iron is also impractical due to the significant duration of the process and the fragility of the resulting surface layer [1].

To ensure high wear resistance of parts made from sparingly-alloyed high-strength cast iron there is a possibility of obtaining bainite structure through isothermal treatment or otherwise [2]. It is known that the material with the bainite structure do not inferior in the wear resistance to the nitride layer. It was indicated that the highest wear resistance, cast irons possess lower bainitic structure [3]. The strength of the isothermal heat-treated cast irons is at a high level [2].

Several works are focused on the study of methods employed for obtaining bainitic cast iron [3-7]. Technique to obtain a matrix of bainite in cast iron in the cast state is complex and requires complex alloying additions. This does not guarantee the homogeneity of the structures and have a risk of developing segregation and micro segregation of elements in the iron composition during solidification.
For cast irons, obtained by casting in a metal mold, this method is unacceptable, as they must undergo graphitizing annealing [6]. The experiments showed that the introduction of 1.0% Nickel, 0.5% copper and 0.5% molybdenum in the alloy, obtained by casting in the mold, leads to the formation of bainite areas in their structure even at slow (furnace and air), cooling after graphitizing annealing. This complicates the machining of castings and does not eliminate the need to additional heat treatment [5].

More appropriate for these conditions is the method of obtaining bainite structure in cast iron via isothermal tempering [3]. It enables the formation of bainitic structure without inclusions of perlite and structurally free ferrite. However, this method requires special equipment and additional production space to accommodate the quenching baths. The complexity of the method is also due to maintaining constant bath temperature and high energy costs.

For cast iron, cast in the mold, especially doped, it is possible to obtain the metal substrate bainite during continuous cooling [6]. The dopants should increase the stability of austenite in the pearlitic region. It is important to understand whether it is possible at conditions of continuous cooling to obtain the bainite structure in cast iron, alloyed with Nickel, copper and molybdenum, and how homogeneous the resulting structure and properties could be.

The presence of structural heterogeneity, as well as difference in proportions of phases in the matrix can significantly affect the mechanical properties of the investigated alloys. It is necessary to evaluate the degree of influence of these factors on the level of guaranteed properties of cast irons.

Thus, in this work the main task was to establish the possibility of obtaining of bainite structure in alloyed Nickel, copper and molybdenum irons, featured in the metal mold during continuous cooling in air.

This treatment can be carried out with the heating higher $A_{1}^{II}$ and higher $A_{1}^{III}$. Apparently, it makes no sense to carry out heating in the inter-critical region, because this can lead to increase in heterogeneity in the matrix of cast iron. In addition, it is important to ensure the stability of the super cooled austenite in the pearlite region of decay that would be better achieved after heating above $A_{1}^{III}$. In this regard, studies were chosen temperature from 870 to 930°C.

Isothermal hardening machined alloy and, for comparison, non-alloyed high-strength cast irons with nodular graphite. Samples of unalloyed iron were studied dependence of bainitic structure from the temperature of isothermal holding. At the same time, the objective was to establish a link between the original structure of the matrix and the speed and completeness of bainite transformation. The latter is important in the development of production technologies for the manufacture of castings of parts of the locking devices from ductile iron in single and metallic forms [6-8].

Temperature of austenitization was 910°C that exceeds 50°C for the $A_{1}^{III}$ investigated alloy. The exposure was 15 min, isotherm temperatures: 350, 400 and 450°C. During quenching, the samples of ferrite and pearlite cast irons were subjected to the same heating in a furnace and simultaneously transferred into the bath. Exposure in the bath was from 30 to 20 hours. After isothermal holding the samples were cooled in water.

It is established that at low shutter speeds in the bath, the iron acquires high hardness, due to presence of a significant amount of martensitic, formed during cooling of the samples to the temperature isotherms in the water. The transformation of bainite in ferrite iron initially develops slower than in pearlite, as evidenced by their high hardness (see table 1).

It is discovered, that the bainite transformation starts to develop intensively in the cast irons with ferrite initial structure after more than a 10-minute exposure. At temperatures of 350°C and 400°C it almost ends at 15-16 minutes (Fig.1). Cooling bath with a temperature of 350°C leads to the formation
of lower bainitic (Fig. 1, 2), and a temperature of 400 and 450 °C - top. Fine precipitation of carbides in the structure of samples treated at 450 °C, with the extracts of more than 16 min are clearly visible (Fig. 3-5).

Table 1. Hardness (HB) high-strength cast iron, casted in a mold, after isothermal hardening.

<table>
<thead>
<tr>
<th>Source structure of cast iron:</th>
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<tbody>
<tr>
<td>Perlitic</td>
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<tr>
<td>512</td>
</tr>
<tr>
<td>444</td>
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<tr>
<td>340</td>
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<td>321</td>
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<td>425</td>
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<td>402</td>
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<td>364</td>
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<td>351</td>
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**Fig. 1. The effect of time aging at 350 °C for isotherm the structure of ferritic ductile cast iron:** a) \( \tau_{isoth} = 2 \) min.; b) \( \tau_{isoth} = 10 \) min.; c) \( \tau_{isoth} = 16 \) min. \( \times 800. \)
Fig. 2. The effect of time aging at 350°C for isotherm the structure of pearlitic ductile cast iron:
A) $\tau = 2$ min.; b) $\tau = 10$ min.; c) $\tau = 16$ min.; d) $\tau = 2$ hours.

Fig. 3. The effect of exposure time with isotherm 400°C on the structure of ferritic ductile cast iron:
a) $\tau = 1.5$ min.; b) $\tau = 10$ min.; c) $\tau = 16$ min.; d) $\tau = 2$ hours.
Studies found that the initial structure of the metallic base of cast iron, cast in the mold, has a significant influence on kinetic parameters of bainite transformation. In the original ferrite matrix, the transformation is quicker and more complete than in pearlite. However, the incubation period in ferrite is more.

**Summary.** Thus, an efficient way of obtaining Manitou patterns in the economically-alloyed iron cast in metal mold by continuously cooled air. The proposed technique provides heat treatment resulting in a rational structure and properties of ductile iron castings for the parts of the locking devices of oilfield equipment.

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**Fig. 4.** The effect of exposure time with isotherm 400°C on the structure of pearlite ductile cast iron: 
(a) $\tau = 10$ min; (b) $\tau = 10$ min.

**Fig. 5.** The influence of exposure time on the isotherm at 450°C the structure of pearlite ductile cast iron: 
(a) $\tau = 100$ sec.; (b) $\tau = 16$ min.; (c) $\tau = 2$ hours.
References


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