Efficient Technologies for Producing Cast Iron Billets and Products with Specified Properties and Microstructure

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Abstract. The article discusses the use of resonant-pulsating refining technology in order to improve the quality of cast iron products. This technology is used in the cast iron production and cast iron mold induction. It is relatively simple and easily fits into existing production. The effectiveness of this technology is at the world's best indicator level. The chemical composition and smelting modes of cast iron influence significantly on the microstructure of gray cast iron. The determining factors are the content of silicon in cast iron, carbon, manganese, titanium and vanadium. The carbon content affects significantly taking into account its content above 3.8%, since this content increases the content of large, ripe forms of graphite in cast iron. Titanium and vanadium also influence significantly on the microstructure of cast iron. These two elements, even in small amounts, affect the size and shape of graphite greatly. It also affects the amount of ferrite, perlite and cementite in the structure of cast iron. Vanadium also affects greatly the service life of cast iron products.

1. Introduction
Metallurgy has a significant impact on key industries in the global economy. Many countries of the world are developing their own metallurgical production to meet domestic and external demand in the required range of metal products.

The main trend in the development of metallurgy and mechanical engineering is to reduce the material consumption and increase the durability of cast iron products. It is possible to increase the service life of products by changing the microstructure of cast iron using new high-performance technologies. The change in structure is achieved by micro-alloying cast iron transforming the size and shape of graphite inclusions. These inclusions increase the strength properties of the parts. It is also possible to use the technology of thermal processing and resonant-pulsating refining. These technological influences significantly increase the operational properties of gray cast iron products.

The introduction of modern resource- and energy-efficient technologies for the production of promising steels and cast iron remains relevant to meet the needs of economic sectors.

2. Formulation of the problem
It is necessary to determine the optimal content of alloying elements for the optimal technology for producing cast iron with the necessary properties. At the same time, it should be noted that optimal alloying could significantly reduce the content of manganese and silicon in heat-resistant cast irons.

The cast iron is industrially used for the manufacture of wear-resistant parts [1, 2] worldwide. The enterprises of Kemerovo region totally produce generally purposed grey cast iron of grades SCH-10 -
SCH-30, grey cast iron of replacement steel casting equipment and mills for ferroalloys, grey half-cast iron of special purpose, and white alloyed cast iron of special purpose. The microstructure of grey and half-cast iron is shown in Figure 1 a), b).

The microstructure of gray cast iron is significantly influenced by the chemical composition and smelting modes of cast iron. The determining factors are the content of silicon in cast iron, carbon, manganese, titanium and vanadium. The carbon content affects greatly its content above 3.8%. Since this content increases the content of large, ripe forms of graphite in cast iron. It is mandatory to refine the metal in a ladle with nitrogen or argon in order to eliminate them or to conduct thermal treatment of the melt in an induction furnace. The influence of silicon also affects the microstructure of cast iron greatly. Thus, when in some cases its content is less than 0.8%, they could observe the appearance of cementite in the structure of cast iron. It is necessary to carry out either additional alloying of the metal in the furnace in order to eliminate it. Modifying the metal with ferrosilicon in the ladle is also necessary. Nitrogen purging also contributes to a favorable cast iron microstructure. Excessive silicon content in cast iron leads to an increase in ferrite in the structure of cast iron. This leads to a decrease in strength in cast iron and a decrease in the performance of cast iron products.

It should be noted that the microstructure of cast iron is also greatly influenced by the mode of thermal treatment of the melt. For example, with a thermal exposure of 10 minutes, when overheating to a temperature of 1520-1550 °C, mainly half-cast iron is formed (Figure 1, a). Heating the metal at the same exposure to temperatures of 1480-1520 °C contributes to the formation of mainly gray cast iron, which has high strength characteristics and high thermal resistance, indicating as the world’s best [3, 4]. The microstructure of cast iron is also significantly affected with the content of vanadium.

3. Research result
The microstructure of cast iron is also significantly influenced by titanium. These two elements, even in small amounts up to 0.1% significantly affect the size and shape of graphite and the amount of ferrite, perlite and cementite in the structure of cast iron. Vanadium also affects the service life of cast iron products greatly. In cast iron of Kemerovo region the vanadium content is usually in the range of 0.04-
0.07%. To select the optimal microstructure and chemical composition of cast iron with a vanadium content of 0.04-0.05% in cast iron and a structural diagram was developed. It allows choosing the optimal chemical composition of cast iron under the appropriate modes of thermal treatment of the melt (Figure 2).

![Figure 2](image1.png)

**Figure 2.** Structural diagram of grey naturally alloyed cast iron. The ranks of the limit region: 4-white cast iron, 3-half cast iron, 2-perlite gray cast iron, 1-perlite-ferritic cast iron (V – 0.04-0.05%).

White and half cast iron are used for producing rolls and other wear-resistant products. Perlite gray cast iron is used for manufacturing engineering products with increased structural strength (beams, brackets). Perlite-ferritic cast iron is used for the manufacture of heat-resistant products, in mechanical engineering and metallurgy (mills, pallets, intermediate bucket covers of continuous casting machines (CCM), machine beds).

Thus, setting the microstructure of cast iron based on the application of methods of thermal processing of the melt allows you to obtain special-purpose cast iron with the specified properties. The use of modern technologies for the cast iron production can significantly reduce the metal content of products. It can also increase their operational stability and reduce the cost of production.

In conclusion, it would be liked to note the following. As it follows from experimental studies, the micro hardness of phosphate eutectic in naturally alloyed titanium and vanadium blast furnace cast iron is 12-15%, which is higher than in cast irons that do not contain these elements [5-7]. Thus, alloying elements are able to neutralize the harmful effects of impurities. It is obvious that detailed research of this problem in the conditions of industrial production is not cost effective. Therefore, in this case, computer modeling is more rational. With the help of a computer modeling you can test theoretical developments, explain and predict phenomena that have not been fully covered yet by other research methods. In addition, the relative cheapness of data acquisition distinguishes the computer modeling. Therefore, a comprehensive study of this problem, which includes not only field experiments but also computer experiments, has been decided to conduct. There is a large volume of results of current computer modeling of binary Fe-C systems [8, 9]. For the Fe-P, Fe-S, Fe-V, and Fe-Ti systems, the volume of research is much smaller [10, 11], but there are studies of impurities of other elements.

For example, the interaction of impurities of various elements with grain boundaries in iron was studied in the work [12-15]. At the same time, the binding energy of clusters containing segregated atoms was calculated with the first-principle modeling. The interaction of impurities and alloying elements was also studied in the work [16]. The energy of dissolution of hydrogen atoms in an iron crystal is estimated as a function of the distance to the alloying elements. In General, it should be noted that in most works on modeling triple Fe-X-Y systems, one of the elements is usually hydrogen or
carbon (see, for example, [17, 18]). For triple systems containing harmful impurities and alloying elements, such as Fe-V-P, the results of research are practically not found in both domestic and foreign literature.

The study resulted to the influence of the alloying elements Ti and V on the process of segregation of impurity atoms P and S. The optimal temperature conditions that promote migration of impurity atoms in the iron matrix were determined. The influence of P and S impurities on the strength properties of the iron polycrystal was evaluated.

Solving these tasks from a scientific point of view allowed us to deepen fundamental knowledge in the field of the influence of impurities on the properties of iron-carbon alloys. From the point of application, the research will improve technologies for updating the mechanical properties of structural materials. In addition, the approaches taken after the study allowed expanding the study and then switching for improving the wearing capacity of the replacing equipment like forging and bluming mills.

4. Conclusion

Thus, microalloying of cast iron with titanium and vanadium increases the strength properties of cast iron significantly thereby increasing the wear resistance of products operating in conditions of abrasive wear and high temperatures greatly. The optimal content of titanium and vanadium in gray cast iron is found to be in the range of 0.04-0.1%. This provides the required strength properties of the parts of the units increasing at the same time their heat resistance. Products made of this cast iron have the required wear resistance and can improve the equipment operational reliability. From a scientific point of view, the solution of these problems has significantly deepened the fundamental knowledge in the field of the impurities influence on the properties of iron-carbon alloys.

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