The results of the application of thermo-time processing and resonant-pulsating refining in the Siberian region of the Russian Federation

D A Lubyanoy1,4, E Yu Pudov1, A V Markidonov2 and A B Efremenkov3

1 Prokopyevsk Branch of T.F. Gorbachev Kuzbass State Technical University, Nogradskaya str., 32 653039, Prokopyevsk, Kemerovo Oblast, Russia
2 Россия, Novokuznetsk Institute (Branch) of Kemerovo State University, 23 Tsyolkovskogo str., Novokuznetsk, 654041, Russia
3 Yaroslav-the-Wise Novgorod State University, B. St. Peterburgskaya str., 41 Veliky Novgorod, 173003, Russia
4 E-mail: lubjanov@yandex.ru
5 E-mail: abe@novsu.ru

Abstract. Currently, in the Siberian region of the Russian Federation, thermo-time processing of the melt and the technology of resonant-pulsating refining of metal are widely used. The article highlights the results of the development and implementation of thermo-time processing and resonant-pulsed refining to improve the properties of the metal. Thermo-time treatment, as a rule, is carried out in induction and electric arc furnaces. It was found that thermo-time treatment allows to significantly improve the quality of the metal, improve the mechanical properties of the products. Resonant-pulsating refining combines melt processing with argon purge and vibrational frequency spectrum processing. The impact of this type of metal blowing on the gas content, the microstructure of cast iron, its mechanical properties, and also the operational properties of the products obtained is evaluated. It was established that the strength properties of cast iron increased by 40–65 MPa, hardness increased by 20 to 30 HB, density – by 100–300 Kg/m³. In addition, it should be noted that the use of the technologies presented in the work can significantly reduce the harmful effects of phosphorus. The operational durability of cast iron products has reached the best domestic and foreign indicators. The developed technologies allowed the implementation to achieve the best performance in the industry with minimal cost. These technologies can be widely used in foundries, electric steelmaking and oxygen-converter shops.

1. Introduction

To increase the service life of machine parts of mining and metallurgical equipment, which is the most important problem of mechanical engineering, technologies for the thermo-time treatment of metal [1, 2] and resonant-pulsed refining (RPR) [3, 4] have been developed and introduced into production. The low life of the products significantly reduces the economic efficiency of technologies and leads to their high metal consumption.
2. Results and Discussion

For the optimal technology for producing cast irons with the necessary properties, it is necessary to determine the optimal modes of iron smelting in electric furnaces [1, 2], the content of alloying elements [5], and the rational technology for out-of-furnace metal processing. Under the conditions of AO EVRAZ ZSMK, gray cast irons for heat-resistant castings and white cast irons [6] for wear-resistant mining equipment (brands IChH17, IChH17N2, IChH22N2MD2F) are produced in a foundry equipped with IChT-10M induction furnaces with innovative sintering technology melt.

It should be noted that vanadium contained in cast iron can significantly reduce the manganese content in heat-resistant cast irons. The task is to determine the concentration of manganese in cast iron with an optimal content of both titanium and vanadium, and optimally alloyed gray cast irons, which have maximum operational stability in the manufacture of replaceable metallurgical equipment, such as slag mills (figure 1) and molds [7].

![Figure 1. Slag for mining and smelting enterprises.](image)

It is known that the properties of used white cast irons are determined by the chemical composition of cast iron, manufacturing technology, the amount and size of carbides [1]. The paper [6] emphasizes the study of the effect on the mechanical properties and workability of white cast irons of carbon, chromium, molybdenum and phosphorus, while the effect of titanium and vanadium has not been studied enough, both in studies of the properties of white cast irons and optimally doped gray heat-resistant cast irons [7–9].

The melting of white alloyed cast iron of the IChH17, IChH17N2 and IChH22N2MD2F grades is performed in a hot crucible after the complete discharge of the previous cast iron melting. Nickel is an undesirable impurity in cast iron IChH17, its permissible content is not more than 0.1%. When melting IChH17, cast iron waste IChH17N2 and IChH22N2MD2F cannot be used. When smelting cast iron of the IChH17N2 and IChH22N2MD2F grades, it is possible to use both domestic production waste and IChH17 cast iron in the charge. The components of the charge during the smelting of these grades are loaded into the furnace in the following order: 1) a combined return of their own production of the same grades is loaded onto the bottom of the hot crucible; 2) load all the estimated amount of pig iron; 3) load carbon ferrochrome FH800; 4) load steel scrap and then layer by layer ferrochrome and steel.
scrap in a ratio of 300/1000. When smelting cast iron IChH22N2MD2F, granular nickel, ferrochrome and ferromolybdenum are loaded into the filling. In the first half of the melting (before melting in a crucible 3–4 tons of liquid metal), the next portion of the charge is loaded into the furnace after the previous one is lowered into the liquid metal. In the second half of the melting, the charge is loaded into the furnace for a well-heated, settled, but not yet melted, previous portion of the filling. Slag during the smelting process is downloaded after the first half of the charge is melted and at the end of the process before adjusting the chemical composition of the metal. When smelting these cast irons for wear-resistant mining equipment, thermo-time processing of the melt (TTP) is mandatory [1, 2]. The essence of the operation lies in the fact that during heating to certain temperatures and holding the melt, homogenization occurs in it and a “short-range order” of the melt is achieved, which improves the mechanical properties and performance of products from wear-resistant cast iron for mining equipment. The temperature of TTP is in the range of 1480–1540°C, the exposure time is 10–15 minutes. When smelting cast iron, IChH17 provide heating up to 1520–1540°C, cast iron IChH17N2 1500–1520°C and cast iron IChH22N2MD2F 1480–1500°C. When smelting cast iron IChH22N2MD2F, overheating of metal above 1500°C is not allowed to avoid subsequent transcrystallization in castings. Deoxidation of the metal in the furnace is carried out by the addition of silicocalcium 10–15 minutes before release from the furnace. Metal is poured into molds from a 2-ton casting bucket. The metal is poured into molds in the presence of a slag cover of molten iron in the casting ladle. The temperature of the metal before leaving the furnace is within the range for IChH17 1520–1540°C, for IChH17N2 1500–1520°C and for IChH22N2MD2F 1400–1420°C. In the ladle before casting, the temperature data must be in the range for IChH17 1460–1480°C, for IChH17N2 1440–1460°C, and for IChH22N2MD2F 1360–1380°C. During the production of wear-resistant cast irons for mining equipment, the chemical composition of cast iron and temperature during smelting are controlled. In the cast iron IChH17 and IChH17N2, the content of carbon, manganese, silicon, chromium and nickel is controlled.

Under the conditions of AO EVRAZ ZSMK, studies were conducted to assess the effect of alloying with titanium and vanadium of gray cast iron [5, 8]. Studies have shown an increase in tensile strength of cast iron.

Figure 2. Large titanium and vanadium carbonitrides in a phosphide eutectic P = 0.30% before purging x800.
As industrial tests have shown, an increase in the strength properties of cast iron leads to a decrease in erosion of products by a falling stream of molten metal. The use of alloying in the conditions of AO EVRAZ ZSMK increased the heat resistance of products [5, 8]. It was noted that the purge of gray cast iron alloyed with titanium and vanadium, nitrogen by the RPR method allows modification of the phosphide eutectic (figure 2, 3) with smaller carbonitrides than before the purge of the metal (figure 4). At the same time, the harmful effect of phosphorus is neutralized. It was established that the strength properties of cast iron increased by 40–65 MPa, hardness increased by 20 to 30 HB, density – by 100–300 Kg/m³.

**Figure 3.** Small carbonitrides in a phosphide eutectic P = 0.30% after purging in resonance mode x1200.

**Figure 4.** Large carbonitrides in cast iron before purging x1200.
The test results showed that a high content of vanadium and titanium in cast iron leads to a decrease in the fluidity of the metal, and leads to the formation of porosity in the castings. To increase the fluidity, ferrophosphorus (P = 17%) was used in the ratio of 800 kg of alloy to a 90-ton bucket. Industrial tests have shown that shrinkage effects and micropores are practically absent in castings doped with phosphorus due to better filling of the molds. The indicated effect was observed when the phosphorus content in cast iron exceeds 0.21% [3].

The analysis of the main phases of cast iron: titanium carbide, phosphide eutectic, and pearlite matrix was carried out by microstructural analysis [3]. When working out the optimal chemical composition, it is necessary to strive for each specific case to obtain a favorable microstructure of cast iron [8–15]. It was found that naturally alloyed cast iron also has all the characteristics necessary to increase the service life of wear-resistant and heat-resistant products: high strength and wear resistance, and in the presence of phosphide eutectic, also good fluidity.

Products obtained from cast irons subjected to thermo-time treatment and resonantly pulsating refining are characterized by low production costs. These products are widely used at enterprises in Siberia and the Urals. In papers [16–20], other ways to increase the operational reliability, durability, and wear resistance of products were also considered. Based on the results of this work, it should be noted that the issue of improving the wear and tear and durability of products must be approached comprehensively, taking into account, on the one hand, the technology of their production, properties of the materials of the products, and on the other hand, taking into account the optimization of operating conditions.

3. Conclusion
It has been revealed that the developed technologies for thermo-time processing of the melt and resonant-pulsating refining allow producing high-quality equipment from gray and white alloyed cast irons. Products made using this technology satisfy customers' requirements. The technologies were introduced on large induction furnaces IChT-10m and in the mold shop in the production and manufacture of small, medium and large castings. Heat-resistant castings made using these technologies have the best performance in the industry. Thus, microalloying of cast iron with titanium and vanadium significantly increases the strength properties of cast iron, thereby significantly increasing the wear resistance of products operating under conditions of abrasive wear and high temperatures. These cast irons are widely used at enterprises in the Urals and Siberia.

References
[1] Tsepelev V S, Selyanin I F, Lubyanoj D A, Baum B A and V’yukhin V V 1995 Steel in Translation 5 42
[2] Lubyanoi D A 2005 Alternative cast irons production technologies for Kuzbass metallurgy 8th Korea-Russia International Symposium on Science and Technology (Tomsk, 2004): collected papers (Tomsk Polytechnic University Publ) 131–33
[3] Lubyanoi D A, Perehodov V G, Foigt D B and Buimov D V 2019 Opyt primeneniya rezonansno-pul'siruyushchego rafinirovaniya v AO «YEVRAZ ZSMK» [Experience in the use of resonant-pulsating refining at AO EVRAZ ZSMK] Ferrous Metals 6 31–33
[4] Andreev V V, Lubyanoi D A, Samsonov Y N, Kaminskaya I A and Lubyanaya S V 2014 Metallurgist 58 492
[5] Lubyanoi D A, Gorkavenko V V, Makarov E S, Kaminskaya I A, Frolov A G and Yakovenko N A 2002 Metal Science and Heat Treatment 44 452
[6] Trukhin V and Trukhin A 2014 Bulletin of Kuzbass State Technical University 2 58
[7] Samsonov Yu 2007 Foundry Production 4 9
[8] Valeev D, Zinoveev D, Kondratiev A, Lubyanoi D and Pankratov D 2020 Metals 10 322
[9] Seidu S O and Ogunniyi I O 2013 Materials Research 16 145
[10] Fras E, Gorny M, Kapturkiewicz W and Lopez H F 2008 Tsinghua Science & Technology 13 177
[11] Ahamed M S, Kumar Y V, Rahman J F, Rakesh S G and Bharat V 2014 International Journal of Engineering Research & Technology 3 424
[12] Fras E, Lopez H, Kawalec M and Gorny M  2015 Metals 5 256
[13] Klancnik U, Habjan J, Klancnik G and Medved J 2017 Journal of Thermal Analysis and Calorimetry 127 71
[14] Riposan I, Chisamera M, Stan S and Bartsow M 2011 China Foundry 8 228
[15] Kumruoglu L C 2009 Materials and Design 30 927
[16] Gabelli A, Morales-Espejel G E and Ioannides E 2010 Evolution 2 25
[17] Mohamed A, Sassi S, Paurobally M 2018 Shock and Vibration 1913289
[18] Kuzin E, Gerike B, Mamaeva M and Singh K 2019 E3S Web of Conferences 105 03011
[19] Mamaeva M and Kuzin E 2019 Matec Web of Conferences 297 03006
[20] Saidi L, Ben Ali J and Fnaiech F 2014 ISA Transactions 53 1650