

Development of technology for high-strength cast iron for manufacturing D49 head of cylinder

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Abstract. This article discusses the technology of melting high-strength cast iron with a spheroidal graphite shape intended for the D-49 type cylinder lid by modifying with magnesium (Mg) in the ladle and gating systems. Today, it is very important for the Republic of Uzbekistan and the CIS countries to create and improve high-strength cast iron production technology to prepare high-responsibility parts of railway transport. Improvement of the mechanical and operational properties of cast iron parts with high strength, as well as development and improvement of the casting technology of the D49 type diesel engine head imported from the CIS countries under local conditions.

1 Introduction

A new machine-building material - high-strength ductile cast iron with spheroidal graphite - combines the high mechanical properties of steel with the manufacturability and convenience of cast iron production. It can replace steel castings and forgings, malleable cast iron, and non-ferrous alloys, and its use instead of gray and modified cast iron increases the operational reliability and durability of machine parts and creates the possibility, in some cases, to reduce their cross-section and weight. Production of high-strength cast iron is based on treating (modifying) its liquid alloy with magnesium or cerium. Magnesium is inferior to cerium in technological properties, but its lower cost has received the greatest application in the industry [1-4].

In modern conditions of railway transport development, the most urgent issue is the production of energy and resource-saving spheroidal graphite cast iron using local raw materials. The purpose of this work is the scientific substantiation of technological developments, introduction into production based on improved technology, and reduction of imports of parts and units made of high-strength cast iron used in production. A distinctive feature of ductile iron is its high mechanical properties due to the presence of largely nodular graphite, which, to a lesser extent than lamellar graphite in gray cast iron, weakens the metal base to a high degree and, more importantly, does not depend on a strong cutting action, due to which graphite inclusions are less susceptible to excitation concentrators. Cast iron with nodular graphite has not only high strength but also ductility.

Obtaining nodular graphite in cast iron with molten additives, inclusions of Mg, Ca, Ce,

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and other rare earth metals (REM).

The chemical composition and properties of ductile irons are regulated by GOST 7293-85 and are marked with the letters "V" - high-strength, "Ch" - cast iron, and a number indicating the average tensile strength of cast iron. For example, VCh 100 is malleable cast iron, tensile strength is 1000 MPa (or 100 kg/mm²).

Malleable cast iron with nodular graphite is the most promising casting alloy that can successfully solve the problem of reducing the mass of structures while maintaining their high reliability and durability.

Ductile iron is used to make critical parts in the automotive industry (crankshafts, gears, cylinders, etc.).

High-strength cast irons are smelted in induction crucible furnaces. The main advantages of induction crucible furnaces are energy release directly in the metal, without intermediate heating elements; intensive electrodynamic circulation of the melt in the crucible, which ensures rapid melting of finely dispersed charge, waste, temperature equalization over the volume of the bath and the absence of local overheating, which guarantees the production of multicomponent, chemically homogeneous alloys; the fundamental possibility of creating any atmosphere in the furnace (oxidizing, reducing or neutral) at any pressure; high performance is achieved due to high specific power values, especially at medium frequencies; the possibility of completely draining the metal from the crucible and the relatively small mass of the furnace lining, which creates conditions for reducing the thermal inertia of the furnace by reducing the heat accumulated by the lining. Furnaces of this type are convenient for periodic operation with breaks between melts and provide the ability to quickly switch from one grade of alloy to another; simplicity and convenience of furnace maintenance, control and regulation of the melting process, wide possibilities of mechanization and automation of the process; high hygiene of the melting process and low level of air pollution [5-7].

The disadvantages of crucible furnaces include complex and expensive electrical equipment, low resistance of the lining at high temperatures of the melt, sharp temperature fluctuations due to the low thermal inertia of the crucible lining (with complete draining of the metal), and the erosive effect of liquid metal during electrodynamic phenomena; the relatively low temperature of the slag brought to the surface of the melt for its technological processing.

Slag in induction furnaces is heated by metal, so its temperature is always lower, as well as the relatively low resistance of the lining at high melt temperatures and the presence of thermal cycles (sharp fluctuations in the temperature of the lining during metal melting).

However, the advantages of induction furnaces over other melting units are significant, and they are widely used in various industries.

2 Objects and methods of research

Experimental melting was carried out at SE "Foundry-Mechanical Plant" in an iron melting medium frequency induction crucible furnace with a capacity of 6 tons with a neutral lining.

During the melting of basic pig iron of VCh50 grades, do not allow sulfur content of more than 0.02%. Otherwise, unstable results on chemical composition and mechanical properties will be obtained, and distorted graphite will be observed in the structure of cast iron.

"Sandwich process". One of the most promising and economical methods of ladle modification of pig iron using low-percentage magnesium ligatures is the "sandwich" process.

This basic modification method provides a special reaction pocket at the bottom of the

pouring ladle. The "light" ligatures pocket is made with a reserve in the upper part so that the modifier can be poured with a fine steel die-cut. A feeding tube with a nozzle (funnel) is used for pouring in as the inoculant is introduced into the ladle, which has already been heated. This method allows:

- provide the required pouring time;
- avoid surfacing of the inoculant when the ladle is being filled (the density of the inoculant is less than the density of the melt);
- to create a necessary area of interaction of ligature with iron melt;
- to cool the pig iron before the beginning of the reaction with the alloy, which positively affects the degree of magnesium assimilation (about 50-60%).

In world practice, one of the most prospective and economical methods of ladle cast iron modification with the use of low percentage magnesium alloying agents is a "sandwich" process, and each enterprise specializing in iron castings modifies this basic method following its individual production peculiarities.

For spheroidizing treatment of iron melt, the most popular is ferrosilicon alloy composition with magnesium mass fraction from 3 to 12%. Advantages of using ferrosilicon magnesium as a spheroidizing modifier:

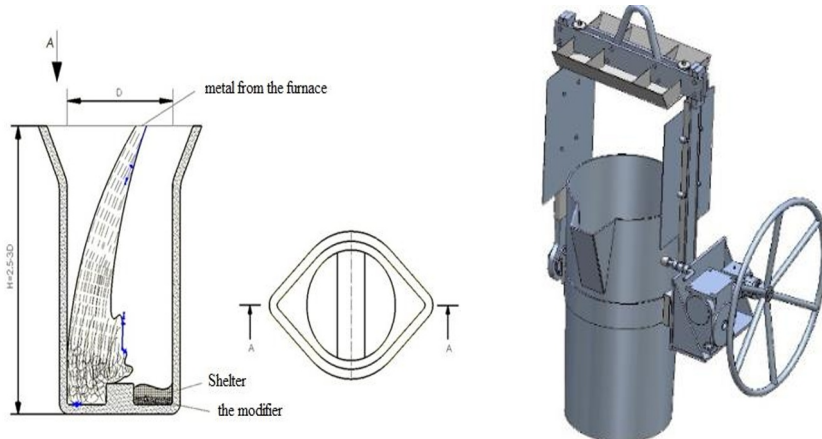


Fig. 1. Sketch of variant of treatment ladle for melt modification according to "sandwich process" technology when using complex iron-silica-based modifiers.

For the desulfurization of cast iron, Refloy®FM (briquette 30x60mm) manufactured by SPE Technologiya was added. The chemical composition of the complex modifier Refloy®FM is shown in Table 1.

Table 1. Chemical composition of complex modifier Refloy®FM

Modifier brand	Mass fraction of major elements, %					
	Mg	Ca	Al	TRE*	Si	Fe
REFLOY® FM	10.0÷12.0	until 6.0	until 1.5	until 5.0	35.0÷44.8	other

*- The amount of rare-earth metals (Ce, La)

Refloy®FM complex modifier is a silicon-containing charge material used in iron smelting instead of FS45 ferrosilicon. In addition to alloying the metal with silicon, Refloy®FM has a refining effect on the metal melt, removing sulfur and phosphorus due to the presence of magnesium and active alkaline-earth and rare-earth elements up to 15%. After the charge is molten, when the produced melt takes up 1/3 to 2/3 of the total furnace volume, REFLOY®FM briquettes are added. The rest of the charge is placed on top of them to

completely cover the briquettes to ensure the most efficient use. The slag must be removed after the entire charge has been melted in the furnace.

The amount of REFLOY®FM briquettes used depends on the process conditions and requirements for the final product and can only be determined experimentally in your foundry. The average consumption of REFLOY®FM is 20 kg per 1 ton of molten metal. Using the melt desulfurization technology described above with Refloy®FM will reduce the concentration of sulfur in the metal.

To obtain castings from cast iron with a spherical shape of graphite, at the bottom of the ladle, add modifiers Spheromag®620L fraction 1,0-10,0mm (spheroidizing) to remove cementite, to align the structure over the cross-section of castings we suggest to use SIBAR®4 fraction for early graphitization and INOCSIL SM80 (inset) for late graphitization.

These materials will ensure the stable production of cast iron with spherical graphite form by ladle modification. The chemical composition of the modifiers is given in Table 2.

Table 2. Chemical composition of modifiers

Modifier brand	Mass fraction of major elements, %						
	Mg	Al	Si	Ca	Ba	La	Fe
Spheromag®620L	5.7÷6.5	0.6÷1.2	44.0÷49.0	1.6÷2.5	-	0.35÷0.6	other
SIBAR®4	-	1.0÷2.0	65.0÷75.0	0.8÷1.5	3.5÷5.0	-	other
INOCSIL SM180	-	3.2÷4.5	70.0÷78.0	0.3÷1.5	-	-	other

To obtain castings from cast iron with a spherical graphite shape, the ladle modification technology "sandwich process" is used, which allows for obtaining stable modification results with minimum consumption of modifiers.

To achieve the best results, metal modification is carried out in a special treatment ladle which differs from traditionally used ladles in foundry production by its geometrical proportions and the presence of a reaction chamber in the bottom part (fig. 1). When using a 0.5-tons turning ladle it is necessary to observe the following technology: the bottom of the treatment ladle should be equipped with a refractory partition which divides it into two chambers: reaction and metal-receiving.

When modifying pig-iron using the "sandwich process", the calculated amount of Spheroidizing inoculant Spheromag®620L in the amount of 1,8-2,0 % of the melt mass is poured onto the bottom of the reaction ladle, and a graphitizing inoculant SIBAR®4 in the amount of 0,25-0,35 % of the melt mass is placed over it. Then modifiers are covered with a small layer

(10-15 mm) of calcined cast-iron steel or shot, which should protect the modifiers from premature interaction with the melt before the ladle is filled. After loading is completed, the level of materials in the chamber should be at the level of the baffle. When releasing metal from the furnace, a jet of metal must be directed into the ladle's metal-receiving chamber so as not to erode the covering material before the ladle is filled to 3/4 of its height. When the pyro effect is finished, slag (reaction products) should be removed, and metal should be poured into the mold.

When preparing the mold, install an INOCSIL SM80 insert for late graphitization on the seating in the gating system of the lower half of the mold (Fig. 2).

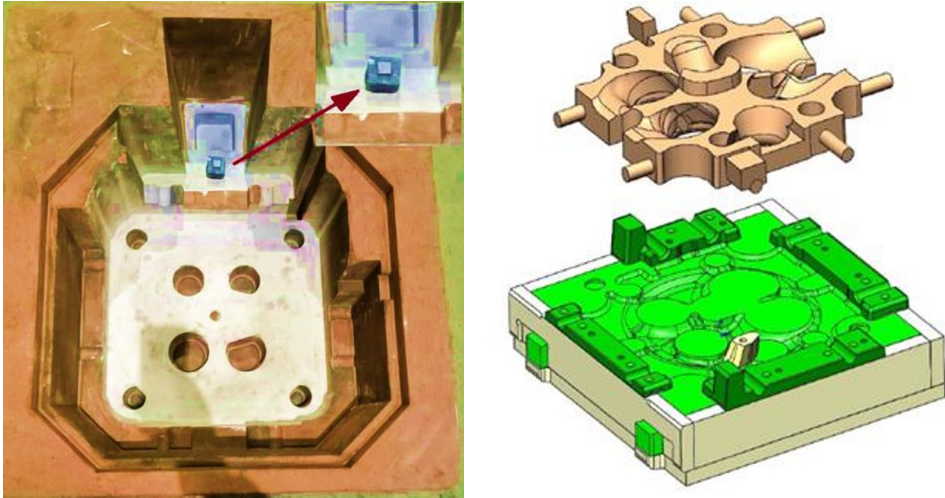


Fig. 2. Lower half-mold cylinder cover type D-49

Since modifiers contain a significant amount of silicon, which is assimilated in the metal by at least 95%, it is necessary to take it into account when calculating the charge for melting and to reduce the amount of ferrosilicon set accordingly.

3 Results and discussion

The melting technology of iron smelting along the melting process is shown in Table 3.

Table 3. Chemical composition of pig iron in course of melting and ladle

№ smelting	№ samples	Mass fraction of an element				
		C	Si	Mn	S	P
1	1	3.039	0.916	0.552	0.020	0.030
	2	3.467	0.882	0.568	0.021	0.029
	bucket	3.380	2.213	0.570	0.009	0.032
2	1	2.554	1.085	0.683	0.026	0.057
	2	3.054	1.140	0.685	0.028	0.052
	bucket	2.979	2.094	0.667	0.023	0.051

Continuation of table № 3.

№ smelting	№ samples	Mass fraction of an element					
		Cr	Ni	Cu	V	Ti	Al
1	1	0.104	0.090	0.080	0.010	0.007	0.003
	2	0.106	0.088	0.080	0.010	0.008	0.004
	bucket	0.111	0.088	0.082	0.011	0.010	0.025
2	1	0.193	0.140	0.158	0.012	0.008	0.014
	2	0.189	0.139	0.157	0.012	0.008	0.012
	bucket	0.197	0.137	0.154	0.011	0.010	0.021

The results of mechanical tests of high-strength cast iron specimens of grade (VCh50) are shown in Table 4, and the microstructure with a spherical form of graphite is shown in Figure 3.

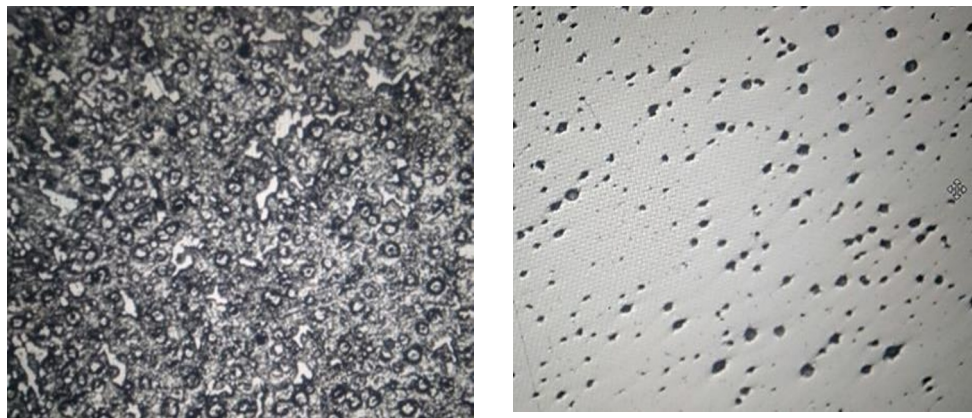


Fig. 3. Microstructure of high-strength cast iron (vch50)

As can be seen from Figure 3, high-strength cast iron (VCh50) with the modification of Spheromag®620L, SIBAR®4, and INOCSIL SM180 are obtained fine-dispersed with spherical graphite, as evidenced by the data.

Table 4. Results of mechanical tests of high-strength cast iron samples

№	Name of controlled parameters	AP item	Normalized values	The actual value of the parameters	
1	Tensile strength:	GOST 7293-85 i. 2.1	At least 500 MPa	Sample №1	535, MPa, U±0.264%
				Sample №2	606, MPa, U±0.264%

As can be seen from Table 4, the complex modification allowed higher AP mechanical properties of time resistance by 7 to 21%.

4 Conclusions

When melting cast iron in induction furnaces, treatment with complex modifier Refloy®FM is 20 kg per 1 ton allowed to reduce sulfur and phosphorus to the required content.

The result of the study shows that during ladle treatment and on the landing place in the gating system of the lower half-mold to set the insert INOCSIL SM80 treatment complex modification allowed higher AP mechanical properties of the time resistance by 7 to 21 %.

Microstructural analysis of metal of complexly modified specimens with a spherical form of graphite. The test results showed the expediency of joint use of a complex modification of cast iron with Spheromag®620L, SIBAR®4, and INOCSIL SM180.

Based on the principle of multilevel modification, the composite material composition based on polyamide 6 modified with glass fiber and a mixture of nanocomponents – copper particles and ultrafine polytetrafluoroethylene is proposed.

The developed composite material exceeds the basic composite in terms of aging and moisture absorption resistance and is a full-fledged alternative to aluminum alloy.

The developed optimization design, and technological and materials science solutions made it possible to recommend a composite material based on glass-filled polyamide 6 as an alternative to the imported analog - aluminum alloy AK12.

References

1. Murot Turakulov, Nodirjon Tursunov, and Shavkat Alimukhamedov, "Development of technology for manufacturing molding and core mixtures for obtaining synthetic cast iron", E3S Web of Conferences 365, 05009 (2023). <https://doi.org/10.1051/e3sconf/202336505006>.
2. Khurshidbek Nurmetov, Alimjon Riskulov, Sadridin Azimov, and Lochinbek Kuchkorov, "Structures of functional elements manufactured using the composite materials", AIP Conference Proceedings 2432, 030059 (2022). <https://doi.org/10.1063/5.0089888>.
3. Khurshidbek Nurmetov, Alimjon Riskulov and Jamshed Avliyokulov, "Composite tribotechnical materials for autotractors assemblies", E3S Web of Conferences 264, 05012 (2021). <https://doi.org/10.1051/e3sconf/202126405012>.
4. Lochinbek Kuchkorov, Shavkat Alimukhamedov, Nodirjon Tursunov, and Otabek Toirov, "Effect of different additives on the physical and mechanical properties of liquid-glass core mixtures", E3S Web of Conferences 365, 05009 (2023). <https://doi.org/10.1051/e3sconf/202336505009>.
5. Shavkat Alimukhamedov, Anvar Nazarov, Akmal Nazarov, and Abdulla Ustoboev, "Estimation of the interval of movement of public passenger transport in the direction", AIP Conference Proceedings 2432, 030055 (2022). <https://doi.org/10.1063/5.0090848>.
6. Doniyor Akhmedov, Shavkat Alimukhamedov, Ibragim Tursunov, Soyib Narziev, and Davron Riskaliev, "Modeling the steering wheel influence by the driver on the vehicle's motion stability", E3S Web of Conferences 264, 05015 (2021). <https://doi.org/10.1051/e3sconf/202126405015>.
7. Tursunov N. K., Semin A. E., Sanokulov E. A. Study of dephosphoration and desulphurization processes in the smelting of 20GL steel in the induction crucible furnace with consequent ladle treatment using rare earth metals. Chernye Metally. 2017. No. 1. pp. 33–40.
8. Otabek Toirov, Nodirjon Tursunov, Shavkat Alimukhamedov, and Lochinbek Kuchkorov, "Improvement of the out-of-furnace steel treatment technology for improving its mechanical properties", E3S Web of Conferences 365, 05002 (2023). <https://doi.org/10.1051/e3sconf/202336505002>.
9. Ryskulov, A.A., Liopo, V.A., Ovchinnikov, E.V. et al. Phase transformations in tribosystems with metal-polymer components. J. Frict. Wear 32, 30–36 (2011). <https://doi.org/10.3103/S1068366611010107>.
10. Marina Radkevich, Tojinur Pulatova, Kamila Shipilova, Oleg Pochuzhevsky, Abdusamin Gapirov and Murat Turakulov, "Possibilities of using lianas for greening automobile roads", E3S Web of Conferences 264, 01034 (2021). <https://doi.org/10.1051/e3sconf/202126401034>.
11. Otabek Toirov and Nodirjon Tursunov, "Development of production technology of rolling stock cast parts", E3S Web of Conferences 264, 05013 (2021). <https://doi.org/10.1051/e3sconf/202126405013>.
12. Tursunov, N.K., Semin, A.E., Sanokulov, E.A. Study of desulfurization process of structural steel using solid slag mixtures and rare earth metals, (2016) Chernye Metally, (4), pp. 32-37.
13. Sherzod Fayzibaev, Oleg Ignatenko, and Talgat Urazbaev, "Development of binding based on b-n-ti-al system compounds for creating a composite instrumental material for a final raining of railway parts", E3S Web of Conferences 264, 04073 (2021).

- <https://doi.org/10.1051/e3sconf/202126404073>.
14. Tursunov N. K., Semin A. E., Kotelnikov G. I. Kinetic features of desulphurization process during steel melting in induction crucible furnace. *Chernye Metally*. 2017. No. 5. pp. 23–29.
 15. Doniyor Akhmedov, Shavkat Alimukhamedov, Ibragim Tursunov, Soyib Narziev, and Davron Riskaliev, "Modeling the steering wheel influence by the driver on the vehicle's motion stability", *E3S Web of Conferences* 264, 05015 (2021). <https://doi.org/10.1051/e3sconf/202126405015>.
 16. Tursunov N. K., Semin A. E., Sanokulov E. A. Study of dephosphoration and desulphurization processes in the smelting of 20GL steel in the induction crucible furnace with consequent ladle treatment using rare earth metals. *Chernye Metally*. 2017. No. 1. pp. 33–40.
 17. Abdusalam Abdukarimov, Shavkat Alimukhamedov, Ismoil Saidakulov, and Sanjarbek Madaminov, "Analysis of a two-roll module with an arcuate displacement of the kenter of rotation of the movable shaft", *AIP Conference Proceedings* 2467, 030029 (2022). <https://doi.org/10.1063/5.0092610>.
 18. Shavkat Alimukhamedov, Anvar Nazarov, Akmal Nazarov, and Abdulla Ustoboev, "Estimation of the interval of movement of public passenger transport in the direction", *AIP Conference Proceedings* 2432, 030055 (2022). <https://doi.org/10.1063/5.0090848>.
 19. Anna Avdeeva, Galina Khromova, and Davran Radjibaev, "Two-axle bogie vibration damping system with additional damping elements", *E3S Web of Conferences* 365, 02003 (2023). <https://doi.org/10.1051/e3sconf/202336502003>.
 20. Yunusov, S., Sultonov, A., Rakhmatov, M., Bobomurotov, T., Agzamov M., "Results of studies on extending the time operation of gin and linter grates", *E3S Web of Conferences* 304, 03028 (2021). <https://doi.org/10.1051/e3sconf/202130403028>
 21. Djurayev, A., Yunusov, S., Mirzaumidov, A. (2020)/«Development of an effective design and calculation for the bending of a gin saw cylinder» // *International Journal of Advanced Science and Technology*, Vol.29. №4, ISSN: 2005-4238, pp. 1371-1390.
 22. Agzamov, M., Yunusov, S., Gafurov, J. On the technological development of cotton primary processing, using a new drying-purifying unit // *IOP Conference Series: Materials Science and Engineering*, Volume 254, Issue 8. *IOP Conf. Ser.: Mater. Sci. Eng.* 254 082017. (2017). DOI 10.1088/1757-899X/254/8/082017