Modification of gray iron produced by induction melting with barium strontium

O G Modzelevskaya[1], A V Feoktistov[1], I F Selyanin[2], A I Kutsenko[3] and A A Kutsenko[4]

[1] Department of Quality Management, Siberian State Industrial University, 42 Kirova Street, Novokuznetsk, 654007, Russia
[2] Department of Material Science, Foundry and Welding Technologies, Siberian State Industrial University, 42 Kirova Street, Novokuznetsk, 654007, Russia
[3] Department of Business and Economics, Siberian State Industrial University, 42 Kirova Street, Novokuznetsk, 654007, Russia
[4] Department of Research Projects, Siberian State Industrial University, 42 Kirova Street, Novokuznetsk, 654007, Russia

E-mail: aak_mail@mail.ru

Abstract. The article provides analysis of results of gray iron experimental melts in induction furnace and the following melt modification with barium-strontium carbonate (BSC-2). It is shown that modification positively affects mechanical and casting properties and as-cast iron structure. It was established that BSC-2 granulated immediately prior to use has greater impact on melt than BSC-2 of the same faction, supplied by the manufacturer.

1. Introduction

Recently, in iron-carbon alloys casting significant attention is paid to liquid melt modification, namely to use of relatively cheap natural materials, represented by complex carbonate ores containing barium and strontium, as modifiers. One of the named advanced materials are barium-strontium carbonate ores, which deposit is being developed in the north-east of the Irkutsk region in Russia, based on these ores the BSC-2 barium-strontium carbonate modifier is industrially produced.

BSC-2 is supplied by “Metalltehprom” SEE Ltd. (Irkutsk) in two main classes by size: 1 class – 10...70mm; 2 class - from powdered to 10mm. Chemical composition of the supplied BSC-2, % is: CaO – 21.5; SiO_2 – 24.8; BaO – 16.0; SrO – 5.5; MgO – 0.9; K_2O – 3.0; NaO – 3.0; Na_2O – 1.5; Fe_2O_3 (FeO) – 4.0; MnO – 0.2; Al_2O_3 – 2.9; TiO_2 – 0.9; CO_2 – 18.0.

This modifier contains barium and strontium, active elements, which by their deoxidizing and modifying effect on steels and cast irons are significantly superior to conventionally used silicocalcium and ferrosilicon.

Industrial testing of BSC-2 modifier is launched 2004 at many machine-building enterprises of “Kamaz” JSC [1, 2], “AvtoVAZ” JSC [3], “Universal” JSC (Novokuznetsk) [4-6]. Results of experimental introduction at metallurgical plant of “Uralvagonzavod Production Association” FSUE of technology of 20GL open-hearth steel modifying with BSC-2 indicates possibility of significant improvement in the range of foundry and mechanical properties of steel and reduction of castings defects along with actually achieved high technical and economic effect for the enterprise [7].

Modifier can form more stable compounds with sulfur and phosphorus than classic fluxing materials used in metallurgy, taking them out of metal into slag, and is more oxygen hungry [8]. Barium and strontium have a modifying effect on ferrite-perlite basis and on large group of non-metallic inclusions, sulphides and phosphides.

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2. Results and discussion

The experiments were conducted to study BSC-2 effect on castings structure and mechanical properties of SCh 15 gray iron. Experiments were performed in the induction casting furnace (ICF) with capacity of 0.06t. The charge of 50 kg weight, consisting of iron LK (40%), casting redistribution (10%), scrap iron (50%), was put into the induction furnace. Chemical composition of the metallic charge is shown in Table 1.

Table 1. Chemical composition of metal charge.

Mass fraction of elements, %											
C	Si	Mn	Cr	Ni	Cu	Ti	V	Mo	S	P	Fe
2.92	2.53	0.46	0.16	0.09	0.15	0.04	0.03	0.006	0.050	0.25	the rest

After melting the charge temperature was driven to 1500°C. The temperature was fixed by tungsten-rhenium thermocouple connected to a digital measuring system [9]. Two meltings we conducted with three options of ladle melt processing:

- without adding the modifier;
- adding the BSC-2 modifier in fraction from pulverized to 10mm, as supplied by manufacturer;
- adding the BSC-2 modifier granulated to the size of pulverized fraction to 10mm instantly before the experiment.

In each variant, 15 kg of liquid metal was consumed. Both meltings were performed in identical conditions with different methods of modifier input. In the first melting the modifier was introduced in the heated ladle under the heel of metal with the help of alloying basket, in the second melting – at the bottom of the ladle. Temperature of metal tapping into the ladle in both cases was 1450±10°C.

BSC-2 was added at the rate of 0.3kg per 50kg of liquid metal, i.e. 0.1kg per ladle. Ladle modifying using alloying basket gave considerable pyroeffect. When modifier was introduced into the bottom of the ladle under metal stream pyroelectric effect was not observed.

From each ladle the following samples were poured at 1350±5°C:

- fluidity sand spiral sample in accordance with GOST 16438, to study melt fluidity;
- V-shape sample for mechanical tests according to State Standard (GOST) 24648, to determine microstructure and hardness;
- 3 cast samples with diameter of 30mm and length of 300mm according to GOST 24648, to study mechanical properties, followed by testing on IK-500 pull test machine;
- wedge sample, to determine cast iron chilling tendency after modification;
- thermal curves were taken during pouring molten iron into die casting sample, to carry out differential thermal analysis (DTA) [10-12].

Study of iron structure was performed on prepared thin sections of samples on Olympus GX-71 optical microscope programmed with Siams Photolab 700.

For metal and slag element composition analysis XRF-1800 wavelength dispersive X-ray fluorescence spectrometer (Shimadzu, Japan) was applied.

Analysis of the results of experimental melts of gray cast iron in induction furnaces with subsequent modification of melt with barium-strontium carbonate showed BSC-2 effectiveness in obtaining fine-grained structure, improvement of casting and mechanical properties of cast iron. Important factor is the state of modifier.

The X-ray spectral analysis showed no Ba and Sr in the samples modified with BSC-2, probably because of their low content. Introduction of modifier did not affect significantly chemical composition of cast iron. Cast iron modification enables reduction of silicon and harmful impurities – i.e. sulfur and phosphorus content.

At cast iron treatment with BSC-2 modifier, an increase of its fluidity (L) is observed. Experimental data on cast iron spiral sample fluidity are shown on Figure 1.

Fluidity of the 1st melt of cast iron modified with BSC-2 granulated as-prepared is increased by 1.7 times compared to unmodified cast iron, it is increased by 1.4 times in comparison with cast iron, modified with BSC-2 as-supplied by manufacturer Fluidity of the 2nd melt of cast iron modified with BSC-2 granulated as-prepared is increased by 1.5 times compared to unmodified cast iron, and by 1.07 times in comparison with cast iron, modified by BSC-2, as-supplied by manufacturer.

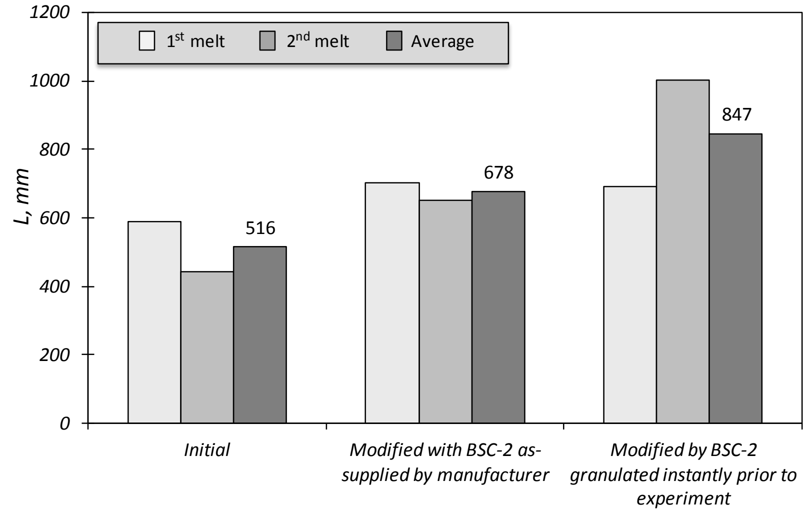


Figure 1. Values of cast iron fluidity for the 1st and 2nd melts.

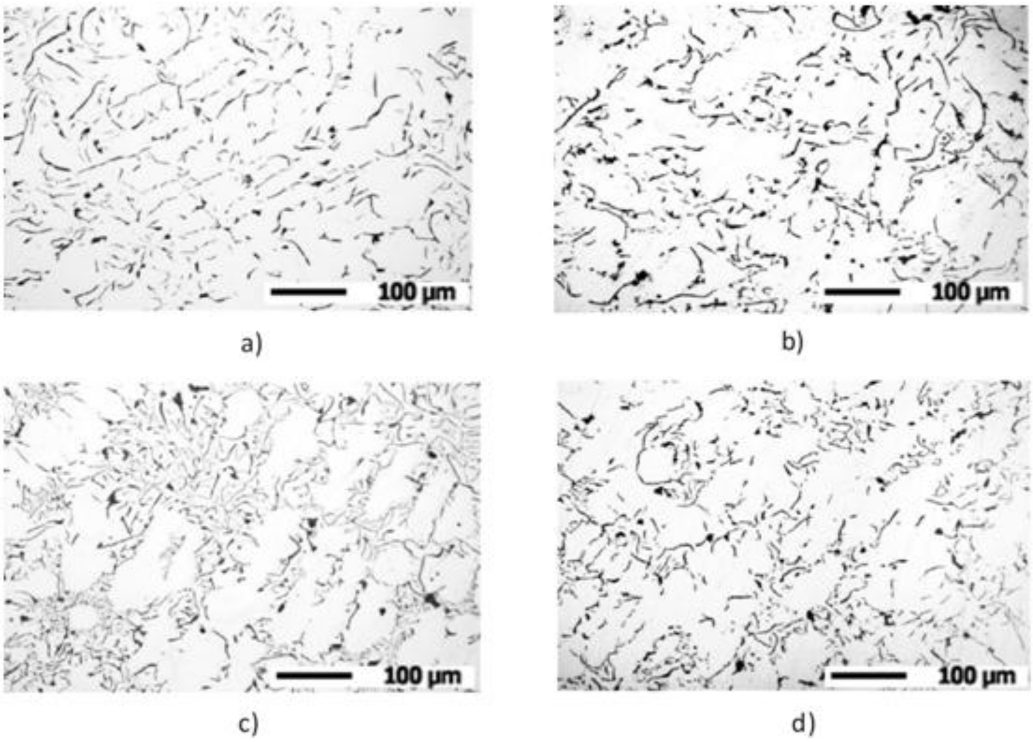
In all the experiments, absence of chill is typical for wedge samples, due to high carbon content in initial cast iron.

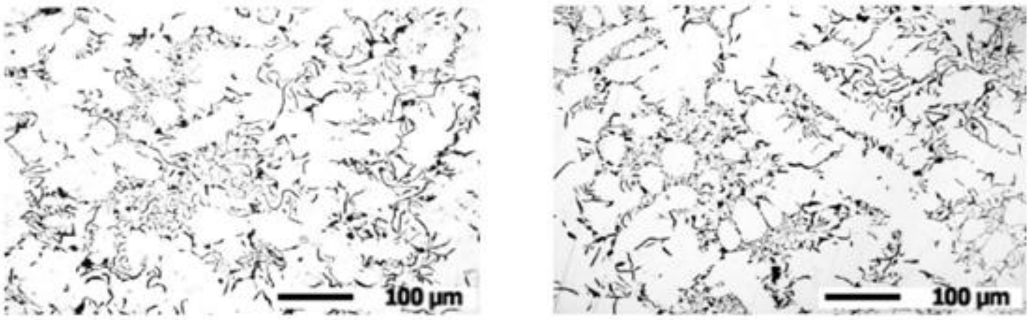
In cast iron microstructure metal base and graphite inclusions were explored. These data are summarized in Table 2 and shown on Figure 2.

Table 2. Analysis of cast iron microstructure.

Melt No.	Sample	Structure by State Standard 3443-87		Size of graphite flakes, micron	
		Metal base	Graphite	min	max
1	Initial without introduction of BSC-2	Pt1 (lamellar perlite) –P (perlite) 6–F (ferrite) 94–PD (perlite, dispersion) 1.0–1.4	PGf (flake graphite inclusions size)1–PGr (flake graphite distribution) 9–PGd (flake graphite inclusions size) 180–PG (flake graphite) 6	5-7	145-155
1	Modified with BSC-2 as-supplied by	Pt1 (lamellar perlite)–P(perlite)45–	PGf (flake graphite inclusions size) 2– PGr (flake graphite	2.5-3.5	80-90

	manufacturer	F(ferrite)55– PD(perlite, dispersion)1.0	distribution)4– PGd(flake graphite inclusions size)90– PG(flake graphite)10		
1	Modified by BSC-2 granulated instantly prior to experiment	Pt1(lamellar perlite)– P(perlite)45– F(ferrite)55– PD(perlite, dispersion)1.0	PGf(flake graphite inclusions size)2– PGr(flake graphite distribution)6– PGr(flake graphite distribution)9– PGd(flake graphite inclusions size)45– PG(flake graphite)10	1.8-2.0	55-65
2	Initial without introduction of BSC-2	Pt1(lamellar perlite)– P(perlite)92– F(ferrite)4– PD(perlite, dispersion)1.4	PGf(flake graphite inclusions size)2– PGr(flake graphite distribution)3– PGd(flake graphite inclusions size)25– PGd(flake graphite inclusions size)90– PG(flake graphite)6	10-14	110-120
2	Modified with BSC-2 as-supplied by manufacturer	Pt1(lamellar perlite)– P(perlite)92– F(ferrite)8– PD(perlite, dispersion)1	PGf(flake graphite inclusions size)2– PGr(flake graphite distribution)8– PGr(flake graphite distribution)9– PGd(flake graphite inclusions size)45– PG(flake graphite)12	3-4	50-60
2	Modified by BSC-2 granulated instantly prior to experiment	Pt1(lamellar perlite)– P(perlite)85– F(ferrite)15– PD(perlite, dispersion)1	PGf(flake graphite inclusions size)2– PGr(flake graphite distribution)4– PGd(flake graphite inclusions size)15– PGd(flake graphite inclusions size)45– PG(flake graphite)12	1.5-2.0	45-55





e) f)

Figure 2. Structure of cast iron, obtained from two melts. Left a, c, e – samples obtained from the 1st melt, x100: a – initial, without introduction of BSC-2; c – modified with BSC-2, as-supplied by manufacturer; d – modified with BSC-2 granulated before the experiment; right b, d, f – samples obtained from the 2nd melt, x100: b – initial, without introduction of BSC-2; d – modified with BSC-2, as-supplied by manufacturer; f – modified with BSC-2 granulated before the experiments.

Microstructure analysis of three samples of cast iron from the 1st melt has shown that modifying leads to grain refinement of metal matrix and change in ferrite-perlite ratio. Refining of graphite inclusions takes place also, graphite is changing its form into vermicular. Greater refining of grains and graphite inclusions is observed when using BSC-2 granulated before the experiment.

Based on the Brinell hardness test results, average hardness value HBav, dispersion D (HB) and mean-square deviation σ(HB) were calculated. 22 measurements of metal hardness were carried out for each sample. Calculation results are presented in Table 3.

Table 3. Results of statistical parameters of cast iron hardness (HB) calculation.

Melt No.	Sample	Specification	Average hardness value HB_{av}	Dispersion*D* (*HB*)	Mean-square deviation σ(*HB*)
1	Initial without introduction of BSC-2	1-1	240	56	7.5
	Modified with BSC-2 as-supplied by manufacturer	1-2	232	40	6.3
	Modified by BSC-2 granulated instantly prior to experiment	1-3	219	14	3.2
2	Initial without introduction of BSC-2	2-1	219	11	3.3
	Modified with BSC-2 as-supplied by manufacturer	2-2	217.7	10.2	3.2
	Modified by BSC-2 granulated instantly prior to experiment	2-3	221.4	6.1	2.5

Study of samples hardness has shown that cast iron mechanical properties after modification are more uniform along the body of casting. This is indicated by decrease in values of dispersion D(HB) and mean-square deviation σ (HB).

Reduction of average hardness HBav value is associated with increase in plasticity of cast iron modified with BSC-2. This is also evidenced by the data obtained as a result of tensile test carried out in accordance with GOST 1497-84 (Figure 3). Tensile strength σ of cast iron from the 1st melt modified with freshly granulated BSC-2 has increased by 32% compared to unmodified iron, and by 15% compared to cast iron modified with BSC-2 as-supplied by manufacturer.

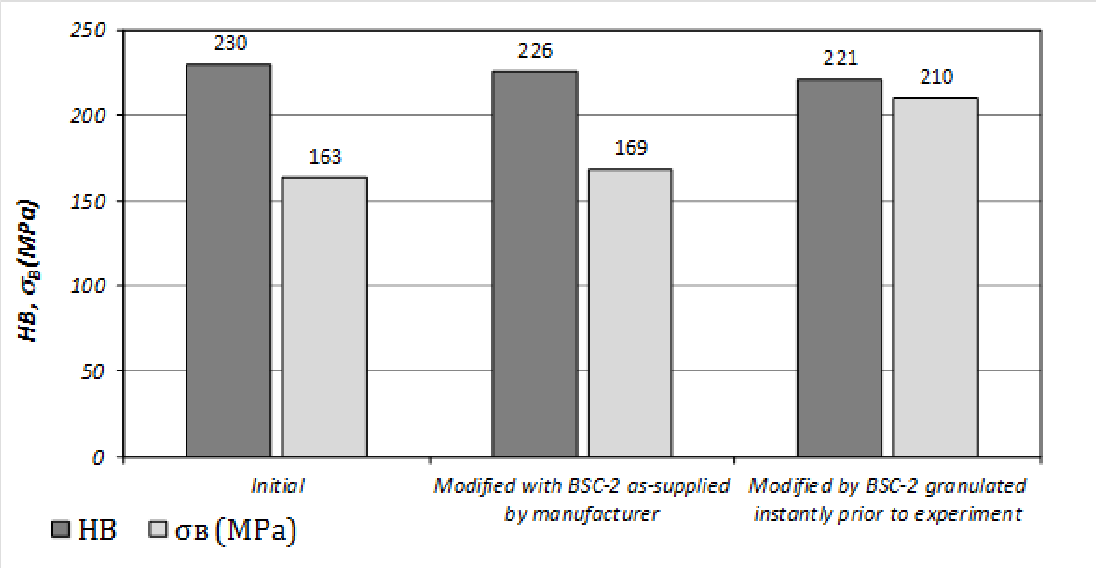


Figure 3. Average values of the Brinell hardness (HB) and tensile strength σ_B (MPa) of cast iron for the 1st and the 2nd melts.

Emission of latent crystallization heat during eutectic transformation is characterized by an increase in melt temperature during eutectic transformation and appeared to be eutectic recalescence (R) [10]. High values of R may indicate uncontrolled formation of graphite inclusions at the early stages of cast iron crystallization process, increasing risk of mold cavity geometry perturbation and incipient shrinkage occurrence. Furthermore, graphite inclusions formation at the early stages of melt crystallization and their growth may lead to a shortage of carbon needed for graphite growth at the end of crystallization cycle, which increases risk of internal shrinkage at microlevel.

Experiments have shown that introduction of BSC-2 modifier into the melt reduces the recalescence value, and modifier granulated before the experiment has lower R values, than the one as-supplied by manufacturer.

Under the influence of BSC-2 modifier temperature range between the lower temperature of eutectic transformation interval (point in which heat loss in the sample are compensated by the heat generated during dendrites growth) and cast iron solidus temperature in cast irons decreased, that indicates reduction of the risk of graphite, carbides and shrinkage defects inter-dendrite distribution in cast iron body.

These are witnessed by the results of metallographic study of samples structure.

3. Conclusions

Analysis of the results of gray cast iron experimental melts in induction furnace with subsequent modification of melt with barium-strontium carbonate have shown the BSC-2 effectiveness in terms of obtaining fine-grained structure, improving casting and mechanical properties of cast iron.

As a result of modification of induction melt cast iron with BSC-2 observed are refining of metal matrix grains and change in ferrite-perlite ratio. Refining of graphite inclusions is also observed, form of graphite becomes more vermicular.

Fluidity of cast iron, modified by freshly granulated BSC-2, has increased by 1.7 times compared to unmodified cast iron. Tensile strength limit σ of cast iron modified with freshly granulated BSC-2 rise by 32% compared to unmodified cast iron. Mechanical properties of cast iron after modification are more uniform along the casting body, hardness HB reduces by 4% correspondingly along with cast iron plasticity increase.

Eutectic recalescence R value reduction for modified cast irons decreases risk of shrinkage and formation of incipient shrinkage microporosity in cast iron body.

Significant factor is the state of modifier. BSC-2 granulated instantly prior to the experiment is has greater effect on melt than BSK-2 of the same fraction, as-supplied by manufacturer.

4. References

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