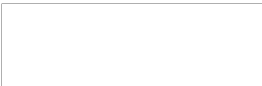




Title: INVESTIGATION OF THE OPTIMUM TECHNOLOGY FOR SMELTING BALL*
BEARING STEEL (USSR) (M. I. Kolosov, I. Ya. Ayzenshtok,
and N. V. Keys)

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INVESTIGATION OF THE OPTIMUM TECHNOLOGY
FOR SMELTING BALL-BEARING STEEL

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To establish the optimum technology for manufacturing ball-bearing steel in the Chelyabinsk metallurgical plant, an investigation has been conducted for determining the effect of the deoxidizing method on the content of nonmetallic inclusions and the surface quality of ingots. Three methods have been used for experimental heats.

1. Deoxidation with carbide slag and lump ferrosilicon

A 30-ton basic electric furnace was used for melting. Furnace charges for melts with boiling comprised 75-90% of carbon steel scrap and 25-10% of pig iron and for remelts - 80% of scrap of the same type steel and 20% of carbon-pure iron. After melting the metal contained 1.25% C and 0.85% O respectively.

In cases of melts with boiling, iron ore in batches of 400-500 kg and lime were introduced into the furnace after the whole charge was melted. Slag was removed 1-2 times during the boiling process and new slag was formed of fluorspar and lime. The rate of carbon oxidation varied from 0.005 to 0.008% per minute. Total time of boiling was from 50 minutes to 1 hour 50 minutes.

Refining was conducted under carbide slag, the mixture for which was composed of equal amounts (25-30 spadefuls) of coke and lime and 6 spadefuls of fluorspar. Deoxidizing with active carbide slag continued for 40-50 minutes.

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Ferrochromium was introduced into the deoxidized bath 1 hour - 1 hour 20 minutes after the beginning of refining. The desirable extent of deoxidizing was determined by shrinkage of the metal in a small crucible. Forty minutes before tapping the carbidic slag had to be converted into white slag by adding only lime instead of the lime-coke mixture. The metal was deoxidized with lump ferrosilicon 15-20 minutes before tapping.

Before tapping the ductility and gas content of the metal was tested using a sample forged in the form of a 12-15 mm thick pellet. Aluminum in the amount of 0.4 kg/ton was introduced into the melt 1-3 minutes before tapping when electrodes had already been lifted. The length of refining varied from 1 hour 45 minutes to 2 hours 30 minutes.

The temperature of the metal at tapping was 1500-1510°. The metal was transferred into a ladle together with slag and, after staying in the ladle for 10 minutes, was poured into square molds with 2.25% taper by the rising method. Time of pouring the ingots to the level of hot tops was 140-210 sec.

After 6-hour cooling in the molds the ingots (1200 kg in weight) were subjected to surface conditioning.

All ingots, according to the quality of their surface, were divided into 6 groups:

ingots acceptable without conditioning	0
ingots requiring conditioning with chipping hammers	I
same, but to a greater extent	II
ingots requiring conditioning by grinding	III
same, but to a greater extent	IV
rejected ingots	V

The surface index was determined by the formula:

$$K = \frac{0.15 + I + II}{0 + I + II + III + IV} \cdot 100$$

where 0, I, II, III and IV denote the number of ingots of the related group.

- 2 -
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The surface index of ingots poured from steel smelted by the process here described varied from 50 to 70%.

Control of the content of nonmetallic inclusions was maintained by examination of 2-3 samples from each heat. Samples of 90 x 90 mm cross-section were taken at a distance of 16-18% of ingot height from the top of the ingot.

The quality of metal produced did not satisfy the necessary requirements, and therefore an attempt was made to find the optimum technological conditions for melting. The effect of separate factors on the steel quality has been studied on 1100 heats, from which number 582 heats were conducted with boiling and remaining heats were made by the method of remelting.

Since the amount of nonmetallic inclusions is a basic quality index for ball-bearing steel, the effect of individual factors in the melting process was evaluated by the content of oxides in the finished steel, taking into consideration that there is a definite relation between contents of oxides and sulfides [1], this relation also being corroborated by the authors' experiments.

Results of examining 210 heats show that the metal smelted with boiling action hardly differs from the metal obtained by the remelting method.

The 1.00-1.25% range must be accepted as an optimum carbon content in metal upon melting-down, because at this content the maximum number of heats has the lowest oxide evaluating number 1.5 or 2.0.

There are several opinions evaluating the role of manganese in the basic process of steelmaking. P. Ya. Ageyev [2, 3] does not recognize any preventive action of manganese in regard to overoxidation of metal or any dependence of the oxide-contamination of finished steel on the manganese content in the first sample of metal right after melting-down. A. M. Samarin [4] plotted, on the basis of theoretical calculations, a curve for the relation between the content of ferrous iron in steel and the content of residual manganese and also demonstrated that manganese does not

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prevent any oxidation of the metal bath. Finally, the practice of the Chelyabinsk metallurgical plant shows that melting without addition of ferromanganese does not impair the quality of metal.

However M. M. Karnaukhov [5] and G. Shenk [6] acknowledge a considerable effect of manganese on decreasing overoxidation of the metal. A. F. Martymov [1] also assumes that at least a 0.15-0.20% content of manganese in metal is necessary for obtaining steel free of nonmetallic inclusions. Investigations conducted by the authors do not corroborate this opinion.

The length of boiling must be between 1 and 1.5 hours and the refining period has to be in the range of 1.75-2 hours. Prolongation of these periods inevitably leads to finished steel contaminated with oxides to a greater extent.

Diffusion deoxidation with carbide slags promotes the obtaining of steel free of nonmetallic inclusions. The content of oxides sharply decreases if the carbide slag carburizes the metal by 0.03%. Further increase of the carbon content is less effective.

374 melts were conducted after changing the smelting technology according to the results of investigations described here; however, the tests showed just a slight improvement in the quality of the metal.

II. Deoxidation with carbide slag and fine ferrosilicon

Three variations of steel smelting have been investigated using this method for deoxidation. In the first of these variations, diffusion deoxidation with ground ferrosilicon has taken place after the addition of ferrochromium. Fine ferrosilicon, mixed with lime, was introduced into the furnace in four to five batches, each containing 40-55 kg ferrosilicon, the total consumption of which amounted to 200 kg of 75% FeSi and 275 kg of 45% FeSi.

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Almost no use was made of powdered coke during the second half of refining since the carbide slag was very stable. All samples of metal during this part of the refining period demonstrated good quiet shrinkage. Forged pellets with drawn-off edges had no traces of gas evolution.

The second variation differed from the first by the amount of aluminum added before tapping: 0.2 kg/ton instead of 4 kg/ton used in the first variation. Altogether, 25 heats were made according to the first variation and 17 according to the second.

In the heats conducted according to the third variation one 500 kg batch of ore was added 2-2.5 hours from the beginning of melting, i.e. before completion of melting-down. Ferrochromium was introduced on the bare metal right after removal of the oxidizing slag. Quartz sand was added to the first carbide mixture. 149 melts were conducted on this variation.

As a result of more complete deoxidation of the slag, the metal made by this variation of technology contained less sulfur (ca. 0.008%) than in the case of deoxidation with lump ferrosilicon (0.011%).

Due to the addition of ore before complete melting-down, the slag was formed earlier. This permitted the use of full transformer capacity for an additional 30 minutes without deteriorating the roof. As a result, the length of the melting-down period was decreased and the temperature of the metal during the boiling period was higher.

This latter factor made it possible to decrease the power supply during the refining period and subsequently to improve the quality of slags due to a decrease in their corrosive action against the lining of walls and roof. Earlier addition of ferrochromium contributed to more complete elimination of nonmetallic inclusions which entered the metal bath together with ferrochromium.

Thus, smelting of ball-bearing steel by the method of diffusion deoxidation with fine ferrosilicon results in obtaining considerably better metal than smelting with the addition of lump ferrosilicon at the end of the melt.

5
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Immediately after removal of the oxidizing slag, partial deoxidation of the metal with aluminum and ferrosilicon has to be conducted, followed by treatment with the carbide slag and final deoxidation with calcium-silicon in the ladle [7].

When such a method of preliminary deoxidation in depth is used the coagulation of nonmetallic inclusions and their floating proceed over quite a long period, actually during the entire refining process which lasts from 1½ to 2 hours.

Calcium-silicon is widely used for final deoxidation of metal in the ladle in the metallurgical plants of Western Europe [8] and the U.S.S.R. [9]. It is usually utilized for deoxidizing metal contaminated with difficultly-soluble oxides [4], since calcium seems to be the most active deoxidizer, and the products of deoxidation, calcium silicates, are usually uniformly distributed in finished steel in the form of small spheroidal particles. This results in obtaining metal free of nonmetallic inclusions and with practically no aluminum oxides.

The thermal effect of calcium oxidation is considerably greater than that of silicon and aluminum oxidation and, therefore, the temperature of the metal on deoxidation with calcium-silicon noticeably rises, facilitating the floating up of the products of deoxidation. In addition, calcium-silicon promotes desulfuration of the metal since calcium is very active in combining with the sulfur of the metal, forming insoluble calcium sulfide which separates from the metal.

Metal deoxidized with calcium-silicon has good casting properties. Experimental heats finally deoxidized with calcium-silicon in the ladle have been conducted in four variations.

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In conducting the heat by the first variation, denoted as IIIA, 800 kg of limestone and 800 kg of iron ore were loaded into the hearth of the furnace before charging the weight of metal comprised of 60-70% of large and 20% of fine carbon steel scrap and 10-25% of open-hearth pig iron.

Limestone and fluorspar were added during melting-down in a quantity sufficient for complete fluxing of the oxides of phosphorus and silicon and for obtaining active slags.

Boiling was carried out intensively, burning out 0.35-0.45% C. The manganese content during the boiling process was not lower than 0.15-0.20% while there was no addition of ferromanganese. Lump 45% - ferrosilicon in an amount calculated to add 0.07-0.10% Si and aluminum in the amount of 0.5 kg/ton were added on the bare metal right after removal of the oxidizing slag and then the reducing slag was made by addition of lime, fluospar and quartz sand. Ferrochromium and ferromanganese were added after the metal was covered with reducing slag i.e. 15 minutes after the beginning of the refining process.

The carbide slag was formed from a mixture consisting of 30 shovels each of lime and fine coke and 6-8 shovels of fluorspar.

Deoxidation with carbide slag was continued for 40-60 minutes. Lump ferrosilicon was added 20 minutes before tapping. Its amount was calculated for an 0.03-0.05% addition of silicon.

The metal was tapped without slag which was removed from the furnace after tapping had been completed. Pieces of calcium-silicon were introduced into the ladle in the amount of 3 kg/ton. The composition of calcium-silicon was: 55-62% Si, 27-28% Ca and 3.0% Al. The temperature of the metal during tapping was 1505-1520°.

In conducting the heat by the second or IIIB variation of the smelting process iron ore was omitted from the preliminary charge. The furnace, right after charging, was run under 240 volts and at full transformer capacity, i.e. 7500 kva; after using 17,000 kwt-hours, it was switched to a medium voltage of 160 v.

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Limestone and fluorspar were added in several batches during melting and the first 400-500 kg weight of iron ore was introduced 2-2.5 hours after switching the current on. The carbon content upon melting-down measured not less than 1.20%. Boiling was carried out vigorously with particular attention to metal heating. The temperature of the metal at the end of boiling was maintained not lower than the tapping temperature.

The content of manganese under normal condition of boiling was not lower than 0.15% without an addition of ferromanganese. At the end of the boiling period the metal contained about 0.80-0.85% C and not more than 0.20% P. Thus, 0.35-0.40% C was burned out for the entire boiling period which continued from 50 minutes to 1 hour 30 minutes.

Immediately after slagging off some ferromanganese was added if necessary, and lump 45% - ferrosilicon in an amount calculated for an 0.07% addition of silicon (taking into consideration a 50% burning out); 0.5 kg/ton of aluminum and ferrochromium calculated for the lower limit of the desirable content of chromium were also added.

The reducing slag was made of a mixture of following components: 80 shovels of lime, 25 shovels of fluorspar and 5 shovels each of quartz sand and crushed chamotte.

As soon as the liquid reducing slag had been formed, the carbide mixture was loaded into the furnace. This mixture comprised 25-30 shovels of fine coke, 30 shovels of lime and 8-10 shovels of fluorspar. Deoxidation with this highly-active carbide slag continued at least 40 minutes. The slag after this process contained not more than 6.80% FeO and not less than 55% CaO.

Charcoal and sometimes fine coke were used for deoxidation of the slag during the second half of the refining period. The carbide slag, toward tapping time, was converted into white slag, which contained not more than 0.65% FeO and at least 55% CaO. The total time of refining was from 1 hour 40 minutes to 2 hours.

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The III-V variation differed in its melting procedure from the IIIB variation only by an extra addition of 0.25 kg/ton aluminum one hour before tapping.

The fourth variation, IIIG, followed the procedure of the IIIB except that aluminum was not used at all.

Steel made according to the IIIB variation happened to be the purest with respect to nonmetallic inclusions. The metals resulting from these different procedures showed little variation in macrostructure. In conformity with these results 200 experimental heats were made by the IIIB method including 59 heats with oxidation and 141 heats by the remelting method. After an additional 269 heats the technology of this method was accepted for production.

Comparison of the technological-economic indexes for 100 experimental heats using calcium silicon (IIIB variation) and 124 heats deoxidized with lump ferrosilicon established, beyond any doubt, the advantages of steel smelting according to the IIIB variation: reducing rejection in rolling more than 6 times, decreasing electric power consumption by 25 kwt-h/ton, improving the surface quality index of ingots^s and others. The following table gives the index values on which the above conclusion is based.

Indexes	Deoxidation with CaSi	Deoxidation with lump FeSi
Total length of making the heat, (hours-min) } with boiling by remelting	8-58	9-08
Refining period included in total time, (h.-m)	7-34	7-55
Consumption of electric power, (kwt.-h/ton) } with boiling by remelting	2-00	2-20
Surface quality index of ingots, ‰	866	893
Rejection in the melting shop, ‰	819	832
Rejection due to poor macrostructure, ‰	107.6	57.6
Rejection by microscopic examination, ‰	2.30	1.40
Rejection in surface conditioning 140 x 140-mm billets, ‰	0.16	0.12
	0.71	5.70
	0.02	0.02

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Indexes	Deoxidation with CaSi	Deoxidation with lump FeSi
Total rejection out of the melting shop	0.89	5.84
Content in slag before tapping, %	0.66	0.73
{ FeO		
{ CaO	53.19	48.88
Content of sulfur in finished steel, %	0.010	0.011

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