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Elaboration of continuous casting technology

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ABSTRACT

of the dissertation submitted for obtaining the scientific degree of Doctor of Philosophy in Technology

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Dissertation work has been accomplished at the department "Materials science and processing technologies" of Azerbaijan State Oil and Industry University.

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GENERAL CHARACTERISTICS OF DISSERTATION WORK

Relevance and development course of topic. One of the most innovative technologies is considered to be electrometallurgy out steel production technologies. Being scientific and technical direction it combines the scientific and technical industry areas with steel and ferroalloy electrometallurgy.

Steel electrometallurgy is a complex process which involves the preparation of raw materials, crushing, grinding, briquetting, moulding, making roll, packaging, agglomeration, delivery of raw materials to the smelter and their position to the furnace and melting of the useful product. During smelting, slags are formed along with the metal, both of which are isolated from the shop, then product is made of usable steel and delivered to the consumer.

One of the most significant issues in electrosteel production is adjustment of chemical composition of steel and its delivery up to the norm in accordance with standard. Of course, main requirement on chemical composition is maximum cleansing of steel from harmful additives and its purification.

Electrometallurgy of steel is multi-phase process. It requires creation, development and elaboration of many smelting, technological and lifting and transport equipment. These equipment should have inherent specific features, unique constructive hubs and aggregates to realize special technologies for each process.

Another most important issue in electrosteel production is process how to cast liquid steel. One of the innovative technologies of recent period is continuous casting process. This process in steel production is regarded to be a concluding level in its transformation to ingot. In this case melted steel is released to workpieces' continuous casting machine (WCCM). Continuous casting technology is considered to be the most prospective and effective method in obtaining workpiece.

Essence of method consists of that liquid steel is poured into water-cooled metal mold (crystallizer), ingot is continuously being pulled from metal mold and then cut up into necessary-sized workpieces.

After the ingot leaves the crystallizer, depending on the direction of movement, the WCCM currently applied in steel melting shops is divided into vertical, radial and curved.

Regardless of the direction of movement of these machines, the intermediate ladle plays an important role in the preparation of steel for casting. Prior to pouring, the heated intermediate ladle is installed in the given position on the crystallizer, water is supplied to the crystallizer and re-cooling is conducted.

The intermediate ladle is filled with metal at a height of 0.4 ÷ 0.6 m and then its connector is opened, the metal is transferred to the crystallizer.

However, as we have mention above, the quality of steel product is formed in the furnace, in the ladle outside the furnace, in the process of continuous casting and processing with subsequent pressure. Each of these processing procedures contributes to the quality of the final steel product.

One of the processes that most seriously affects the quality of steel is purification. For example, the use of the method of blowing powder-like reagents in the process of electrosteel melting can be considered one of the most effective innovative technologies. However, there is no definite answer to the question of which reagent is more effective and at what extent in introducing to metal in separate points of the technological chain.

There are problems in electroplating that require extensive research in the processes of purification in ladle and furnace, continuous casting, and the pressure processing processes of obtained steel ingot. The approach to these problems is relevant, taking into account the day-by-day growing demands of the industry, and determines the scientific direction of this dissertation case.

Goal and objectives of study is study of the processes of purification and deoxygenation in the furnace and ladle with powder to improve the quality of steel in electroplating using metal waste.

To achieve this goal the following issues have been set:

1. Determining the role of electric melting in the production of reinforced steels and the advantages of out-of-furnace processing in the production of high quality reinforced steels;
2. Clarifying the thermodynamic and kinetic factors affecting the purification process of reinforced steels in the ladle before continuous casting by blowing with powders;
3. Studying the effect of technological parameters on the process of desulfurization of steel in the casting ladle by blowing powders;
4. Studying and developing recommendations on the process of deoxygenation in steel casting ladles by blowing metal powders;
5. Developing recommendations for improving the quality of steel after blowing with powders in the ladle and furnace and the application of study results in production.

Methods of study. The issues raised in the dissertation work were solved on the basis of theoretical and experimental research conducted in laboratory and production condition. The reliability of the obtained results was confirmed by experimental data using modern equipment, devices and measuring instruments, including X-ray phase analysis, microstructure and element analysis studies.

Main considerations of the defense:

1. Determining the role of electric melting in the production of reinforced steels;

2. Clarifying the thermodynamic and kinetic factors affecting the purification process of reinforced steels in the ladle before continuous casting by blowing with powders;

3. Studying the effect of technological parameters on the process of desulfurization of steel in the casting ladle by blowing powders;

4. Studying and developing recommendations on the process of deoxygenation in steel casting ladle by blowing metal powders.

Scientific innovation of study. The thermodynamic and kinetic factors of the purification process in the out-of-furnace processing of steel by blowing powders of different dispersions and compositions have been studied and clarified. For the first time, powder mixtures were selected on the basis of MgO, and the effect of such a composition on increasing the durability of the ladle was substantiated. The amount of sulfur in the slag phase and the desulphurization effect were determined during the blowing with powders. It was found that the degree of purification of the slag drop created by the powder mixture, the size of its contact with the metal determines the adsorption regime of sulfur depending on the time. The adsorption regime expresses the ratio of thermodynamic and kinetic factors of the process.

It was determined that the degree of desulfurization of steel directly depends on the composition and consumption of the powder mixture. New equations of the basic slag and its viscosity were obtained by blowing with slag mixtures. As the basicness of the slag increases (B> 5) (CaO / SiO2), its viscosity becomes higher.

Depending on the amount of FeO in the slag, the degree of desulfurization has been specified. Excessive increase of FeO in the slag does not allow to increase the desulfurization more than 50%, and as a result, it is observed by resulfation of the steel in this long-term blowing. At the same time, in the presence of FeO in the slag, the rate of resulfation in steel increases during long-term blowing with argon.

Thereotical and practical significance of the study. Conducted studies have confirmed the effectiveness of out-of-furnace steel processing in terms of quality assurance by blowing with various powder mixtures.

The scheme of placement of technological equipment for carrying out of out-of-furnace processing with powders in the process of continuous casting in electroplating is given and the characteristics of the equipment are specified.

Purification and oxygenation technologies of reinforced steels by blowing non-metallic and metal powders have been developed, and the selected efficient regimes have provided elaboration of the structural and strength characteristics of the steel.

Approbation and application. Main considerations of dissertation work have been discussed and highly appreciated in following conferences and seminars:

International scientific-technical and scientific-practical conferences:

1. VII International scientific–practical conference "Modern problems of machine theory», June 7, 2019, Novokuznetsk city, Russian Federation.
2. International conference named "Reconstruction and restoration in postconflictual states" devoted to 100^{th} anniversary of Azerbaijan State Oil and Industry University, February 25-26, 2021.
3. International scientific-practical conference «Youth, science, education: Actual issues of achievement and innovation». Penza city, RF, April 27, 2022.

Republic scientific and technical conferences:

4. Scientific and technical conference "Perspectives for the development of maritime transport" dedicated to the 96th anniversary of National Leader Heydar Aliyev, ADDA, April 04, 2019.
5. XVII International scientific and technical conference "Problems of water transport" dedicated to the 99th anniversary of the National Leader Heydar Aliyev, ADDA, May 05-06, 2022
6. Scientific seminars of department "Materials science and mechanical engineering" , 2018-2021.

General volume of dissertation with characters separately noting the volume of structural units. Dissertation work consists of introduction, 5 chapters, computer text of 158 pages, 57 figures, 25 tables, literature list in 108 numbers and Appendix. Title page and contents (3481 characters), introduction (8511 characters), chapter I (36696 characters), chapter II (41404 characters), chapter III (53496 characters), chapter IV (34078 characters), chapter V (32311 characters), conclusion (5152 characters) and used literature list (13926 characters). Volume of dissertation consists of 229055 characters excluding figures, tables, graphics and literature list.

Publication rate: Main content of dissertation work has been reflected in 16 scientific works.

MAIN CONTENT OF THE WORK

In introduction the relevance of the dissertation topic and the main considerations for defense have been formed.

In Chapter I Analysis of the requirements for construction fittings shows that their quality, including strength and technological properties must be quite high. The literature review has shown that electroplating is the most innovative technological process in improving the quality of construction fittings. It was determined that the application of re-smelting technology of metal wastes to ensure the quality of steels and increase productivity can be considered the most effective method in electroplating.

The role of out-of-furnace processing methods in the production of high quality steels is undeniable. Thus, the intensive development of out-of-furnace processing methods and conducted new researches provide a scale of production and a wide range of ferroalloys. It was found that the use of innovative methods of alloying, out-of-furnace processing and casting process plays a great role in improving the quality of reinforced steels.

A number of methods of out-of-furnace processing of liquid steel, including with vacuum, inert gases, synthetic poses, are widely used in electroplating. Analysis of the literature data shows that one of the most effective methods of out-of-furnace processing is the purification process at deeper layers of metal using a powder-like reagent. However, the lack of researches in this area prevents the widespread application of out-of-furnace processing [1][1].

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[1] Oxygen removal from steel by blowing of mixtures of slag and metal powders. A.T.Bayramov.

The features of the workpieces' continuous casting process of pasta were analyzed which are considered to be the most innovative casting technology. After removal of ingot in the crystallizer, the existing types of WCCM were analyzed for the direction of its movement and the characteristics of the technological process applied in "Baku Steel Company" CJSC were described. In order to reduce the construction height of WCCM, machines with new construction have been developed and applied in electroplating.

New measures carried out in the field of continuous casting technology and ensuring the quality of ingots was analyzed. The analysis showed that various casting technologies, including the application "melting on the melting", heating the intermediate ladle before casting, optimizing the selection of casting speed, adjusting the casting nozzle of liquid metal, methods of feeding metal to the crystallizer, giving slag mixture to the crystallizer, blowing of liquid metal with inert gases, optimization of re-cooling mode, etc. serves to improve the quality of steel products in electroplating process.

The analysis showed that the role of quality purification in the deep layers of liquid metal can be irreplaceable in the production of higher quality construction steels by blowing with powders of different compositions and sizes in the smelting furnace and intermediate ladles. Researches are carried out in various areas, including the selection of the composition of powder-like reagents, their stage and amount of administration, etc. We believe that conduction of such researches is relevant and is the issue on the agenda in electroplating.

In Chapter 2 The thermodynamics of the purification process was analyzed in the out-of-furnace processing of steel by blowing various powders. In previous studies, CaO constituted main component of the blown powders. However, for the first time we recommended the use of MgO in the composition of powder and carried out a thermodynamic assessment of its effect on the process. The purpose of selecting MgO as the main component in the powder was to protect the casting ladle masonry from premature collapse [7][2].

The chemical composition of the blown powders and slag was studied after the metal was released. It was found that if ladle masonry operates 60÷70 time without repair when used a mixture of lime and fluorspar, ladle masonry has been useful to unrepaired use of 100 times in some cases in the use of magnesium oxide. The main parameters of blowing of powder mixtures of magnesium oxide, lime and fluorspar (2:1:1) to metal in the base masonry ladle have been determined.

Table 1

Chemical composition of blown powders and slag appeared in the ladle after release of metal

Material	Mass amount of components, %								
	MgO	CaO	MnO	FeO	SiO_2	Al_2O_3	CaF_2	other	S
Powder: magnesium oxide	90,01	7,8	–	0,2	1,2	–	–	0,75	0,025
lime	91,2	8,01	–	0,55	2,8	1,26	–	2.213	0,027
flourspar	2,55	0,09	–	0,49	3,94	0,80	82,42	9,80	0,054
mixture of magnesium oxide and flourspar	70,14	0,4	–	0,50	3,06	1,05	20,62	4,179	0,027
ladle slag	60,5	8,7	0,3	0,3	16,4	6,3	7.5	–	–

$[S]_o=0{,}020\%+m^{/}S_p\cdot 100\%=0{,}020\%+100/3\cdot\Delta S_o$, here m_p-mass of furnace slag taken equal to 3% of metal mass.

The equilibrium content of sulfur in the known composition and amount of steel and slag, i.e. its minimum concentration

[2] Improving the quality of steel after blowing with powders in the furnace and ladle. A.T.Bayramov.

achieved in steel can be calculated by the degree of use of the desulfurization ability formed by blowing metal with mixtures of slag. In industrial conditions, a mixture of powder of 50% MgO, 15% lime and 22% fluorspar was used for desulfurization of reinforced steels in the base masonry ladle. The amount of blown powder mixture was 0.7 ÷ 1.4% of the spilled metal mass. The chemical composition of the powder is given in Tables 1 and 2.

Table 2

Chemical composition of slag formed in blowing of steel in the ladle with mixture of magnesium oxide, lime and fluorspar (2:1:1)

Steel, slag (brand of alloy)	Amount of components in slag, %						
	MgO	CaO	MnO	FeO	CaF_2	SiO_2	Al_2O_3
Ст3	57,61 (1,029)	8,42 (0,210)	0,34 (0,005)	0,49 (0,007)	10,37 (0,133)	16,63 (0,277)	5,49 (0,054)
Ст3	57,38 (1,025)	8,35 (0,213)	0,35 (0,005)	0,50 (0,007)	1020 (0,131)	16,85 (0,281)	5,56 (0,055)
Steel 20	57,48 (1,027)	8,44 (0,211)	0,34 (0,005)	0,49 (0,007)	10,34 (0,133)	16,67 (0,2278)	5,50 (0,054)
Steel 30	57,60	8,41	0,34	0,49	10,37	16,63	5,49
Intermediate slag, %	57,52	8,45	0,34	0,49	10,32	16,70	5,51
Last slag, %	59,04	7,53	0,30	0,49	11,67	14,82	4,94
Intermediate slag brought to the following systems:							
$MgO-Al_2O_3-SiO_2$	72,15	–	–	–	–	20,95	6,90
$MgO-SiO_2-CaF_2$	68,05	–	–	–	12,20	19,75	–

Note: In circular parentheses shown values of “n”, i.e. number of component mole in 100 grams’ slag.

The powder mixture is given in the jet of technically pure argon brand A by immersing the metal in formed ladle to a depth of n ~ 1/3. The duration of blowing of powders to ladle made up 2.2 ÷ 3.2 minutes at the value of excess pressure ≥ 0.8 MPa in the argon belt [2][3].

The nature of changes in the amount of sulfur in the metal during the blowing of magnesium oxide, lime and fluorspar was studied in the ladle. At the same time, the amount of sulfur and the desulfurization effect were determined in the slag phase. Equilibrium coefficients of sulfur distribution between metal and slag were found in the ladle through blowing of powders. It was found that the degree of use of desulfurization of the slag phase in the blowing of metal with powders depends on both the composition of the slag phase and the duration of its interaction with the metal. The change in the amount of sulfur in the metal by blowing the powders in the ladle is shown in Table 3.

The kinetics of the out-of-furnace processing of liquid steel with powders has been analyzed. Determined that degree of use sulfurization ability of slag drop is identified by dimensionless time of its contacting with metal (Fourier parameter) $\theta = \tau_O D / r_0^2$ and dimensionless parameter defining adsorption regime of sulfur with slag drop; $\alpha = L_s D / K r_o$. Here parameter α characterizes the ratio of thermodynamic and kinetic factors of the desulfurization process [3][4].

The process of adsorption of sulfur with slag droplets under the conditions of metal blowing with easy-melting slag droplets occurs in a mixed kinetic mode, and the rate of heterogeneous desulfurization reaction may coincide with the rate of diffusion of sulfur in slag droplets. Creation of smaller slag droplets is required to achieve a high rate of desulfurization of the metal without blowing

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3 Study of the kinetics of the process of steel desulfurization in the ladle by blowing powders. R.I.Kerimov, A.T.Bayramov.

4 Impact of the composition and consumption of desulfurizing powder mixture on the purification process of steel. M.B.Babanli, A.T.Bayramov.

with powders. This allows these tiny droplets to penetrate deep into the metal.

Table 3

Amount of sulfur in metal during blowing of magnesium oxide, lime and flourspar in the ladle (2:1:1)

Number of alloy	$[S]_{initial}$	$[S]_n$	$[S]_O$	$[S]_S$	$\Delta[S]_O$	$\Delta[S]_S$	$\Delta[S]_n$	$[S]_\infty$
1	0,017	0,0135	0,0101	0,0058	0,0069	0,0115	0,0046	0,0038
2	0,0165	0,0135	0,0102	0,0069	0,0063	0,0096	0,0033	0,0038
3	0,0160	0,0145	0,0085	0,0048	0,0075	0,0118	0,0037	0,0030
4	0,0155	0,0110	0,0100	0,0058	00,055	0,0097	0,0042	0,0040

Note: $[S]_{initial}$ – initial amount of sulfur in furnace in the beginning of recovery process;

$[S]_n$ – amount of sulfur in furnace at the end of recovery process;

$[S]_o$ – amount of S after releasing metal to the ladle (before blowing);

$[S]_s$ – after finishing of blowing;

$[S]_\infty$ – equilibrium amount of sulfur;

$\Delta[S]_o=[S]_{initial} - S_o$ – change in sulfur amount until blowing;

$\Delta[S]_s=[S]_{initial} - [S]_s$- after blowing;

$\Delta[S]_n=[S]_o - [S]_s$- as a result of blowing.

The process of adsorption of sulfur with slag droplets under the conditions of metal blowing with easy-melting slag droplets occurs in a mixed kinetic mode, and the rate of heterogeneous desulfurization reaction may coincide with the rate of diffusion of sulfur in slag droplets. Creation of smaller slag droplets is required to achieve a high rate of desulfurization of the metal without blowing with powders. This allows these tiny droplets to penetrate deep into the metal.

In Chapter III the effect of technological parameters on desulfurization of steel in out-of-furnace processing was studied by blowing powder reagents. In this regard, the effect of the composition and consumption of the desulfurization mixture of powder in the ladle was assessed. The dependence of the degree of desulfurization of steel was determined on the composition and consumption of blown powder reagents. As the consumption of the powder mixture increases during blowing, the rate of desulfurization of the steel gets higher.

It has been determined that the powder mixture has a sufficient effect on the rate and completeness of the removal of sulfur from the metal in the blowing of the electric steel in the mixture of slag and metal powder. The parameters of the experimental-industrial alloys of reinforced steels in blowing with powders in the ladle were specified. The change in the amount of sulfur in the steel was determined depending on the duration of blowing with powders in the casting ladle with different powder-like mixtures. As the blowing durability increases, the amount of sulfur in the steel decreases, but too much increase can cause resulfation [4][5].

The addition of magnesium oxide to traditional powder mixtures has led to the following advantages: 1) desulfurization goes rapidly and completely; 2) traditional metallurgical materials are used; 3) a relatively not high amount of silicon calcium is accompanied by a small increase in the amount of silicon in steel.

New equations of basicity and viscosity of slag were obtained by blowing with powder mixtures. Graphics of the dependence of the rate of desulfurization in blowing of the mixture of argon gas and slag on the composition of the slag has been built. Information on the chemical composition of the slag mixture formed during the blowing of powder mixtures in argon gas, the rate of desulfurization of steel and the basicity of the slag were clarified. Concomitantly, graphics of the steel desulfurization rate were built after and at the time of the release of the slag on the metal surface.

The effect of the ladle masonry was studied on the rate of desulfurization in the blowing of liquid steel with powder mixtures. It was found that the material of the ladle masonry significantly affects the composition and basicity of the resulting slag. The low basicity of the slags leads to the rapid collapse of the ladle's

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[5] Deoxygenation of steel in the ladle by blowing metal powders. M.B.Babanli, R.I.Kerimov, A.T.Bayramov.

masonry. Thus, a large part of the magnesium and calcium in the slag interacts with the ladle masonry and gradually collapses it [5][6].

The completeness of desulfurization of steel by blowing with powders depends, above all, on the initial amount of sulfur in the metal. Figure 1 shows that under other equal conditions, there is a linear dependence of the final amount of sulfur on the initial amount of sulfur in the steel in the metal blowing in the ladle with a mixture of 70% MgO, 20% CaO and 10% CaF2. The degree of desulfurization of steel depends on the degree of deoxygenation of the metal. It is known that a high degree of desulfurization is achieved in well-deoxygenated steel processing. The degree of deoxygenation of steel relatively depends on the rate of oxygen entry from the slag and masonry and deoxygenation reaction rate. The deoxygenation processes of the steel and recovery of the slag take place at the same time as the intensive metal mixing and the slag in the ladle. In this case, the activity of oxygen in the liquid metal is determined mainly by the amount of FeO and MnO in the slag.

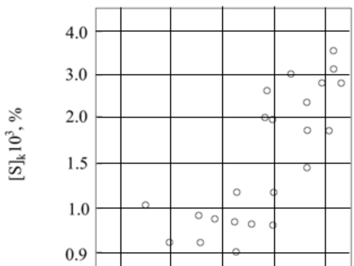

Figure 1. Dependence of sulfur amount in the metal on its starting concentration at the end of blowing with powders

[6] Analysis of the thermodynamics of the desulfurization process of steel in the ladle by blowing powders. M.B.Babanli, R.I.Kerimov, A.T.Bayramov.

Depending on the final amount of sulfur $[S]_s$ maximum values of oxygen activity in steel have following numbers:

$[S]_s$, %	0,0028	0,0048	0,009
$a[O]\cdot10^4$	1,08	1,88	3,6

In accordance with some data speed of oxygen entering steel from ladle's masonry in blowing with CaC_2 powder accounts for %/min.: 0,007 (chamotte), 0,0035 (Al_2O_3) and 0 (dolomite).

The rate of oxygen infiltration from the masonry also depends on the intensity of mixing, the degree of deoxygenation of the metal, the volume ratio of the surface area, and so on. The oxygen infiltration from the masonry increases the activity of oxygen in the metal, reduces the coefficient of sulfur distribution between the metal and the slag, and obviously reduces the rate of desulfurization [6][7].

In figure 2, results of desulfurization in the high clay-soil masonry ladle (60% Al_2O_3) in blowing of aluminum with silicon calcium of deoxygenated steel (1÷2 kg/t) were depicted by having aluminum amount in metal ≤0,0038% and 0,010÷0,020%. The amount of aluminum rises from 40÷70% (if exists ≤0,0038% Al) up to 60÷85% (if exists 0,01÷0,03% Al) in the steel. The desulfurization process and production of small amounts of sulfur in the metal are provided under the condition that after blowing the amount of aluminum in the steel is ≥0.02% and the amount of oxygen is ≤0.002%, respectively [7][8].

Depending on the amount of FeO in the slag, the degree of desulfurization is specified. It was found that the increase in FeO in the slag is accompanied by resulfation instead of desulfurization. The rate of resulfation increases as the duration of blowing increases when liquid metal is blown with argon in the ladle with different amounts of FeO. However, the presence of caps in the ladles

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[7] Impact of the composition and amount of slags on the desulfurization process of steel. M.B.Babanli, R.I.Kerimov, A.T.Bayramov.

[8] Improving the quality of steel after blowing with powders in the furnace and ladle. AUAC, Scientific publications. A.T.Bayramov.

improves the blowing conditions of the metal, reduces oxidation and metal loss.

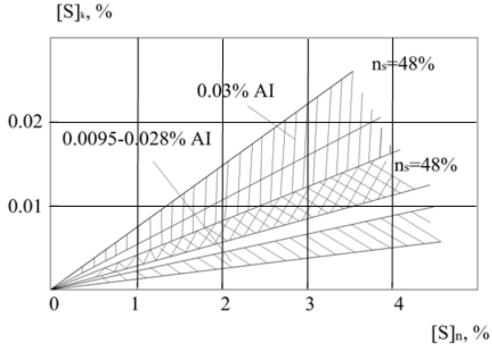

Figure 2. Dependence of the degree of desulphurization of aluminum on the amount of aluminum in steel when blown with silicon calcium powder (1 ÷ 2 kg / t) in high clay-soil masonry ladle (60% Al_2O_3): $\eta_s=([S]_b-[S]_s)/[S]_n\cdot 100\%$, where $[S]_n$ and $[S]_b$– start and end amount of sulfur in metal

The layout plan of equipment is proposed for the processing of armature electric steels in the ladle. The scheme of the ladle-furnace device for blowing of powder reagents to the liquid metal is given. The effect of the chemical composition of the liquid metal on the degree of desulfurization of steel in blowing with powder has been studied and the significant effect of the initial amount of sulfur on the metal on the completeness of desulfurization has been defined.

In Chapter IV deoxygenation of reinforced steel in the furnace was considered by blowing metal powders and slag mixtures together. It was found that the effect of deoxygenation in the blowing of steel with powders of magnesium alloys differs little from the effect obtained in blowing with classical deoxygenators such as aluminum. There is a sharp increase in the rate of removal of oxygen from the steel in excessivity of aluminum and introduction of magnesium. In compliance with $MgO–Al_2O_3$ phase diagram in blowing with powders globular oxides MgO type in the steel are emerged in recovery of clay-soul under liquid state on 1600^{0}C [8][9].

Blowing of steel with Mg-Si-Ca alloy has a serious impact on the morphology of calcium-magnesium aluminates. In this case, the resulting globular elements are more dispersed than those obtained by processing with silicocalcium or Ca-Si-Mn alloy. The removal of sulfur from the steel during processing by blowing powders of magnesium alloys is more effective than blowing with conventional technology. As the consumption of blown magnesium increases, the amount of oxygen falls sharply in the steel.

A scheme was developed for selecting powder material for its blowing in the ladle depending on carbon amount in the steel. In accordance with this scheme it is recommended to use only magnesium powder in the scarcity of carbon amount in the steel, magnesium carbide in medium number and majority of silicocalcium. The general equation for blowing of flux and silicocalcium has been obtained with certain probabilities. The actual and calculated amount of oxygen is determined in blowing of powders of different composition.

Compliance with the law of removal of oxygen from steel is explored in blowing of a mixture of slags and metal powders. In this composition, several effects have been identified in the blowing of steel. The main effect is to reduce their consumption by increasing the purification capacity of the powders used. Note that oxygen amount reduces in the steel, magnesium's consumption rises when blowing durability increases in blowing with such compositions.

The scores of linear, globular and oxide elements formed in steel during deoxygenation by blowing of mixtures of slag and metal powders were determined. Identified that the biggest, including 4-scored oxides, non-aluminum powder-like mixtures in blown mixture are acquired in the blowing process. Studied the dependence of the degree of contamination of steel on the ratio of silicocalcium and

[9] Mechanical properties of purified electric steel by blowing powders in the ladle. A.T.Bayramov.

aluminum in mixture. This ratio has been shown to be more effective at ratios around 1:2 and 1:3 [9][10].

Results of evaluation of metal for maximum score of dotted, linear and globular oxide elements (Fig. 3) show that in this case exact dependence of maximum score of oxide elements is observed on ratio between silicon calcium and aluminum content and powder-like mixture used for blowing of liquid metal in the ladle. In the absence of aluminum in mixture, spread metal is featured by the highest score of linear oxides and globules; The maximum score of linear oxides reaches 3, and that of globular elements reaches 4. As amount of aluminum in mixture increases, a constant decrease is observed in maximum value of globular elements. The maximum value of linear oxides more sharply decreases in minimum addition of tested amount of powder-like mixtures (ratio of Ст30: Al=1:0,5).

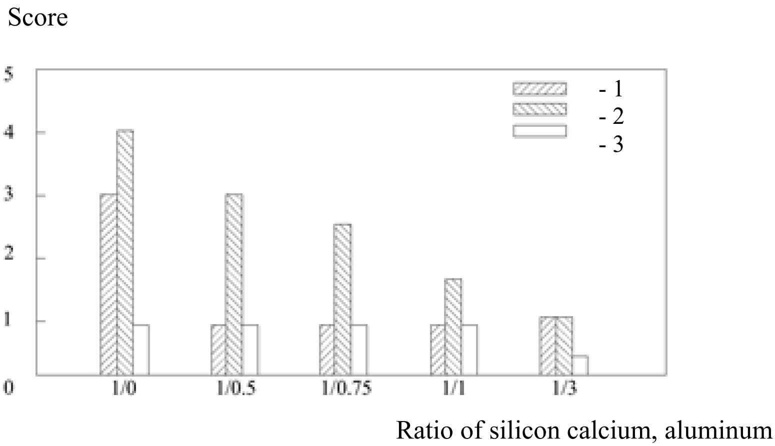

Figure 3. Maximum score of oxide elements in steel Ст3 at various ratio of silicon calcium and aluminum in the mixture:
1–linear oxides; 2–globules; 3–dotted oxides

[10] An impact of the ladle lining on the refining of reinforced steel when blowing with powders. M.B.Babanlı, R.I.Kerimov, A.T.Bayramov, I.B.Abbasov.

Further growth in amount of aluminum in mixture does not affect maximum score of these elements. The maximum score of point oxides remains low enough (1 score) and is practically not dependent on amount of aluminum in the mixture. Thus, based on evaluation of maximum score of these elements, it can be concluded that ratio of silicon calcium and aluminum (1:2) ÷ (1:3), which is the purest in terms of oxide elements and the smallest in terms of element size, is also used for blowing in the ladle in described mixture of powders.

The conformity of the ratio of silicon calcium and aluminum in the mixture to the pollution of oxide elements can be explained as this follows. It is known that the application of silicon calcium for the deoxygenation of steel causes a reduction in the amount of linear elements formed in the deoxygenation of the metal, usually with an increased amount of aluminum. However, when silicon calcium is incorporated into insufficiently deoxygenated steel, relatively large globular elements are formed. Similar large globular elements have been followed in the blowing of a mixture of non-aluminum powders. The addition of aluminum powder to the mixture leads to the fact that a part of the oxygen in the metal is used to interact with the aluminum. Due to the decrease in the amount of oxygen that reacts with magnesium, the sizes of the globular elements are getting lower. However, the presence of magnesium in the deoxygenation mixture prevents the formation of large-linear oxides. In the result of going reaction $mMg+nAl_2O_3=mMgO \cdot nAl_2O_3$ globulation of oxide elements occurres. The view and distribution of elements in such elements are presented in Figure 4. According to some information, magnesium converts all clay-soil elements into liquid aluminate of magnesium, if its amount in the metal is three times more than the total amount of oxygen. The inclusion of Mn-Al alloy powder in the mixture of lime, fluorspar and silicon calcium leads to a further increase in the purity of the steel due to non-metallic oxide elements [10][11].

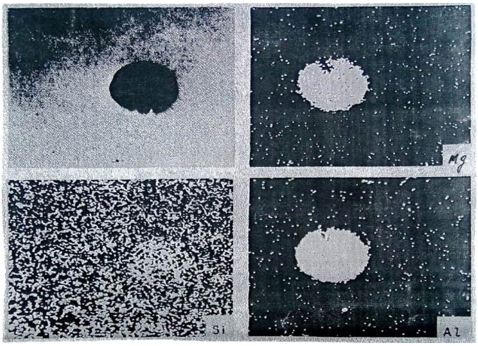

Figure 4. General view and distribution ×4000 of magnesium, silicon and aluminum on characteric area of globular oxide elements in steel Ст3 after blowing of magnesium oxide, fluorspar, silicocalcium and aluminum mixtures

Thus, the processing of steel in the ladle with a mixture of slag and metal powders is an effective way to increase the degree of steel deoxygenation, improve this for non-metallic elements, and regulate the shape, amount, and sizes of the elements.

Score degrees of oxide elements in the reinforced steel, as well as linear, globular, and dotted elements has been determined at different ratios of silicon calcium and aluminum powder mixtures the blowing with different powder mixtures. In this case, it is produced at the ratio of silicon calcium and aluminum powder mixture (1:2) ÷ (1:3), the purest in terms of oxide elements and the smallest in terms of elements' sizes, in the blowing in the ladle.

It was determined that the processing of electric steel in the ladle with metal powder is the most effective processing method to increase the degree of deoxygenation, improve the structure for non-metallic elements, regulate the shape, amount and sizes of elements.

[11] Improving the quality of billets by applying electro-magnetic metal stirring. R.I.Kerimov, A.T.Bayramov.

In Chapter V the nature of the distribution of oxide, sulfide and non-metallic elements has been considered in the melting of reinforced steel in the furnace and ladle and in the blowing of metal with slag and metal powders. The maximum score for the metal oxide elements melted by conventional technology was 1/3 in the new technology, and 1/2 times lower for the sulfides. Therefore, only traces of fragile and plastic silicates are observed in the reinforced steel obtained using new technology. Contamination with non–metal elements has sharply dropped in application of the new technology.

Analysis of the amount of non-metallic elements released from reinforcing steel by electrolysis, their chemical composition and structure according to petrographic and X-ray structural analysis data shows that their amount is significantly less in the steels obtained by new technology compared to the steels obtained by conventional technology. It has been revealed that analysis of chemical composition of non–metallic elements consisted of Al_2O_3, SiO_2 and MgO. Petrographic and X-ray structural analysis confirmed that phase traces of $MgO \cdot Al_2O_3$, $MgO \cdot 6Al_2O_3$ and $CaF_2 \cdot 5Al_2O_3$ existed in the structure.

The study of the mechanical properties of reinforced electric steel obtained by new technology has shown that their strength and plasticity properties were higher than steel melted by conventional technology. Reducing amount of phosphorus in the reinforcing steel obtained by new technology leads to an increase in its impact viscosity. Concomitantly, reduction of phosphorus in the steel plays the role of main reason for a significant reduction in cracks [11][12].

In the test of transverse and longitudinal samples, the dependence of the impact viscosity has been built on the amount of phosphorus in the reinforcing steel and the nature of the change in impact viscosity has been determined at different test temperatures. The analysis shows that it is less sensitive to temperature change in relation to fitting melted using the new technology.

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[12] Improving the quality of billets by applying electro-magnetic metal stirring. R.I.Kerimov, A.T.Bayramov.

The strength characteristics, including strength range, fluidity range, impact viscosity, relative elongation, and relative shrinkage of samples from re-melted alloy steels by blowing of powders in the furnaces and ladle have relatively significantly values in relation to the steels melted by conventional technology and from shikhta.

Preparatory actions are taken for application of processing technology in the furnace and ladle by blowing of powders of new technology developed at "Baku Steel Company" CJSC. For this purpose, measures are being developed for the complex solution of preparation, storage, transportation, loading of the powders and blowing of the powders into the arched furnace and ladle [12][13].

GENERAL OUTCOMES

1. Blowing of liquid metal with powders in the ladle has been suggested in order to purify reinforced steels in electric melting and for the first time MgO has been offered instead of CaO, which is the main component of powders. It was found that the use of MgO as a purifying component-powder material in the melting of low-carbon reinforcing steels is more effective in relation to CaO. At the same time, the use of MgO as the main component in the power mixture prevents the rapid collapse of the casting ladle. The thermodynamics of the purification process in the out-of-furnace processing of steel by blowing various powder mixtures has been analyzed and the existing considerations in this field have been expanded [13][14].

2. Kinetics of sulfur conversion in liquid metal has been learned in blowing of reinforcing steel in ladle with powder mixtures based on magnesium oxide, sulfur amount in slag phase and desulfurization effect have been determined. In other words, equilibrium coefficients of sulfur distribution have been found

[13] Role of elecroplating in the production of construction fittings. Mammadov A.T., Bayramov A.T., Khankishiyev I.A.

[14] Deoxygenation of reinforcing steel with the application of complex out-of-furnace processing. RRPCS-2021. "Reconstruction and restoration in postconflictual states" Conference materials. Bayramov A.T.

between metal and slag in liquid steel blowing with powder mixture. Both composition of slag phase and duration of its interaction with metal are so significant in metal desulfurization in blowing of liquid metal in ladle with magnesium-based powder mixtures.

3. Kinetics of the reinforced steels with out-of-furnace processing process has been explored, dependence of purification ability of slag droplet has been identified on its contacting time with metal. Determined that adsorption of sulfur in the blowing of the metal with easy-melting slag droplets occurs in a mixed kinetic regime, and it is possible that the rate of heterogeneous desulfurization reaction may coincide with the rate of diffusion of sulfur in slag droplets. Presence of smaller slag droplets in the blowing makes their inclusion into metal depth necessary and it is clear that this allows the occurrence of desulfurization in the metal at deeper layers.

4. The effect of technological parameters has been studied on purification process in the melting of reinforced steel by blowing powder reagents. Noted that as the consumption of the powder mixture increases during blowing, the degree of desulfurization of the steel gets higher. Determined that excessive increase of desulfurization time can lead to resulfation of liquid metal [14][15].

5. Desulfurization with the addition of magnesium oxide to known grinding mixtures goes rapidly and completely, traditional metallurgical valuable materials are not used, the use of silicocalcium in the powder mixture is accompanied by a small rise of silicon in steel. Information has been clarified on the composition of the slag, the degree of steel desulfurization and the basicity of the slag, formed in the blowing of magnesium oxide-based powder mixtures in argon gas.

6. Effect of ladle masonry to the degree of desulfurization has been determined in the blowing of liquid steel with powder mixture, material of ladle masonry extremely affects the composition and

[15] Out-of-furnace processing in the production of high-quality steels. A.G. Velichko, S.R.Rakhmanov, M.B.Babanli, A.T.Mammadov, A.T.Bayramov.

basicity of resulting slag. Ladle masonry collapses fast in the low basicity of the steel. At the same time dependence of the degree of desulfurization has been specified on the amount of FeO in the slag. Increase of FeO in the slag can be observed by resulfation of the metal.

7. Steel deoxygenation process steel in the ladle has been studied by blowing with metal powders. Effect of deoxygenation in the blowing of mixtures of magnesium alloys and slag together differs little from the effect obtained in blowing with classical deoxygenators such as aluminum. Calcium element in blowing of steel in the ladle with Mg-Si-Ca alloy affects seriously the morphology of magnesium aluminates. In this case, the resulting globular elements are more dispersed than those obtained by processing with silicocalcium or Ca-Si-Mn alloy.

A scheme of powder material was selected for blowing in the ladle depending on carbon amount in the steel: it is recommended to use magnesium powder in scarcity of carbon, silicocalcium in medium number and magnesium carbide in majority [15][16].

8. Score degrees of oxide elements in the reinforced steel, as well as linear, globular, and dotted elements has been determined in the blowing with different powder mixtures. In this case, it is produced in the ratio of silicon calcium and aluminum powder mixtures (1:2) ÷ (1:3), the purest in terms of oxide elements and the smallest in terms of element size, which used in the blowing in the ladle. Blowing of electric steel in the ladle with metal powder can be regarded as the most effective method in comparison to other processing elements.

9. The distribution nature of oxide, sulfide and non-metallic elements in reinforcing steel has been explored after blowing with slag and metal powders in an electric furnace and ladle. The maximum score for the metal oxide elements melted by conventional technology was 1/3 in the new technology, and 1/2 times lower for

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[16] Reserves for increasing efficiency of out-of-furnace processing of electric steel. A.T.Bayramov.

the sulfides. Only traces of fragile and plastic silicates are observed in the reinforced steel obtained using the new technology [16][17].

Mechanical properties of the reinforced electric steel obtained using the new technology were much higher than the steel obtained by the conventional technology. At present, a special actions' plan for the application of new technologies is developed at "Baku Steel Company" CJSC.

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