Improvement of the Quality Group of Critical Railway Castings from 110G13L Steel

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ABSTRACT

This paper presents the results of industrial tests to improve the technological process of smelting 110G13L steel to increase mechanical properties, improve the quality group and operational reliability of critical railway castings, and reduce the cost of steel. Using statistical and regression analyses, the advantages of a comprehensive approach were revealed on metal when using innovative diffusion deoxidizers in the following areas: organizing early slag induction during charge melting, increasing the efficiency of diffusion deoxidation of steel due to the use of a Diffusion Aluminum-containing Deoxidizer (DAD), and extra furnace treatment of the melt in a ladle with a Universal Refining Mixture (URM), providing an adsorption-flotation method of steel refining. The main advantage of the diffusion deoxidizers developed is that they have a high dispersion that significantly increases their reactivity. The implementation of the proposed directions to improve the technological process of smelting 110G13L steel for critical railway castings in combination with the optimization of the chemical composition of steel and slag allowed a significant increase in the number of first-quality group smelts from 29% to 71% while reducing cost.

Keywords-steel; slag; critical casting; innovative diffusion deoxidizer; chemical composition optimization

I. INTRODUCTION

Having at one time given a new round in the development of the metallurgical industry, Hadfield steel became indispensable for a large range of castings and has not lost its relevance to this day. 110G13L has properties that have practically no analogs and are so necessary in many production areas [1]. The toughness of austenite, wear resistance, and low hardness of Hadfield steel with a high tendency to work hardening have led to no alternative application where the material must withstand and absorb high impact loads without rapid failure, starting with military armor, tank and tractor tracks, jaws and crusher cones, teeth and front walls of an excavator bucket, bodies of vortex and ball mills, and ending with prison bars on windows [2]. Today, foreign and domestic Hadfield steel grades have been developed for the needs of mechanical engineering, mining equipment, and transports [3-5].

Hadfield steel is indispensable for the production of critical rail crosses and turnout castings on railway tracks. One of the factories in the Russian Federation produces such castings from high-manganese steel of the austenitic class, grade 110G13L. The casting requirements are regulated by GOST 7370 [6]. The chemical composition of the steel according to the requirements of GOST 7370 is given in Table I.

TABLE I. CHEMICAL COMPOSITION OF STEEL ACCORDING TO GOST 7370

Mass fraction of elements (%)					
C	Mn	Si	Al	No more	
				P	S
1.00-1.30	11.50-16,50	0.30-0.90	0.0025-0.011	0.09	0.02

Depending on the mechanical properties of high-manganese steel for casting cores and solid crosspieces, the metal group is determined by the lowest mechanical property indicator according to Table II.

TABLE II. PHASE-MINERALOGICAL COMPOSITION OF EKIBASTUZ COAL ASHES (AVERAGE WT %)

Indicator	Mechanical properties for metal groups		
	I	II	III
Temporary resistance, σt, N/mm^2, (kgf/mm^2)	St. 883(90)	St.785(80) till 883(90) incl.	From 687(70) to 780(80) incl.
Yield strength σ02, N/mm^2, (kgf/mm^2), no less	355 (36)	355 (36)	355 (36)
Relative extension, δ, %,	St. 30	St. 25 till 30 incl.	From 16 to 25 incl.
Relative narrowing, ψ, %,	St. 27	St. 22 till 27 incl.	From 16 to 22 incl.
Impact strength, KCU, J/cm^2(kgf•m/cm^2)	St.2,5 (25)	St. 2,0 (20) till 2,5 (25) incl.	From 1,7 (17) to 2,0 (20) incl.

The mechanical properties of steel for smelted castings and their compliance with metal groups according to GOST 7370 were analyzed at the plant in 2021. The results are presented in Figure 1.

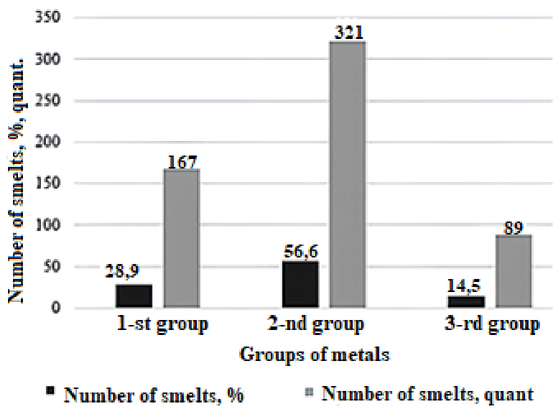

Fig. 1. Distribution of smelted castings in 2021 by metal group.

As can be seen in Figure 1, there were no defects in the melts with mechanical properties below the requirements of GOST 7370 for group 3. At the same time, the number of heats in the first group was only 28.9%, which, given the increasing requirements of Russian Railways for the operational reliability of castings, is clearly insufficient. Therefore, the plant set the task of increasing the mechanical properties of steel and the number of heats that meet the requirements of group 1 [7-11].

This study focused on increasing the mechanical properties and quantity of 110G13L steel melts from the first group for critical railway castings (railroad switches and crosspieces).

II. RESEARCH METHODS

Steel was melted in the plant in arc furnaces with the main lining DSP-6N1. The metal loading capacity was 8 tons. Charge materials consisted mainly of scrap carbon steel, return of own production, as well as ferroalloys: ferromanganese FMn 78, FMn 88, and ferrosilicon FS 45. Technical aluminum was used for the deoxidation of steel. 70-75% of the melts were performed using the oxidation method. Iron ore pellets were used for baling. As returns and defects accumulated, steel was melted using the remelting method in 25-30% of the total number of casts. The molds were poured from a stop bucket with a capacity of 8 tons and the filling temperature was 1460-1480°C.

The chemical composition of the steel was determined using a Foundry-Master optical emission spectrometer. Samples poured with a spoon into a metal mold were used as samples. The slag was removed with a spoon in the furnace and poured onto a metal plate. The quality of the slag was visually and chemically analyzed. Sample blanks were obtained to determine the physical and mechanical properties of steels by pouring test bars into dry core molds following GOST 977-88 No. 1.

This work processed statistically the research results using Statistics & Analysis software. The significance level for the calculations was set to 0.05 [12]. Arithmetic average values of the chemical composition of the metal and slag, pouring temperature, as well as indicators of variations in the average values that characterize their stability were determined. The fewer variations that fluctuate around the average, the more reliable it is. The coefficient of variation most clearly characterizes the homogeneity of properties, since it shows the relative measure of fluctuations of a characteristic. The latter was calculated as the ratio of the standard deviation to the arithmetic mean [13].

The chemical composition and mechanical properties of 110G13L steel were regulated by GOST 7370 (Table I). However, the wide limits of the concentrations of carbon, silicon, and manganese, all other things being equal, do not ensure constant mechanical and operational properties for castings. Deviation of chemical elements (C, Si, S) within the limits of the requirements of GOST 7370 and minor changes in the melting conditions of 110G13L steel lead to significant fluctuations in parameters of structural strength, such as σ_t, σ_{02}, δ, ψ, and K_C of the alloy [14, 15]. To optimize the chemical composition of steel, it is advisable to perform a regression analysis of the dependence of mechanical properties on the chemical composition [16].

In [17-19], it was shown that the operational durability of castings made of 110G13L steel is directly related to its quality, which can be improved by extra-furnace complex deoxidation, refining, and modification. An increase in the structural strength of 110G13L steel can be achieved by optimizing the heat treatment regime [20, 21] and alloying with Mo, Ni, V, and other elements [22-26]. However, this increases the cost of castings and does not always provide stable results.

Therefore, to increase the mechanical properties of steel and the number of melts in the first quality group, a different path was chosen by introducing a complex effect on metal in three directions to improve the smelting of 110G13L steel using innovative materials developed by LLC Metallurg SOAL [27]. The first direction of improvement of the process was to organize the early introduction of slag during the melting of the charge. To achieve this, limestone was loaded onto the bottom of the furnace in an amount of 50 kg/t of liquid with an RSh flux of 5 kg/t of liquid. The low-melting slag quickly filled the wells cut by the electrodes in the charge and shielded the arcs, so all the heat was spent heating the metal. At the same time, manganese waste decreased by 50% and the melting time of the charge decreased by 10 minutes. The concentrations of Mn and Fe oxides in the slag decreased, making it easier to carry out the recovery period of the smelting in the future. The second direction of improvement was the more efficient diffusion deoxidation of steel. For this purpose, a Diffusion Aluminum-containing Deoxidizer (DAD) was used in an amount of 6 kg per 1 ton of liquid steel, which can foam and effectively deoxidize slag. The third direction of improving the technological process is the out-of-furnace treatment of the melt in a ladle with a Universal Refining Mixture (URM) that provides an adsorption-flotation method to refine steel. Gases formed during ladle processing increase the thickness of the metal, adsorb non-metallic inclusions, and carry them into the slag. This also leads to an increase in the mechanical properties of steel.

The main advantage of the developed materials is that they have high dispersity, which significantly increases their reactivity [28]. In addition, they are packaged in 3 kg bags, which significantly facilitates the work of workers, the accuracy of the dose, and the control over the rational use of materials [27-30].

III. RESULTS AND DISCUSSION

After implementation, statistical and regression analyses of the indicators of 306 melts were carried out. The results of statistical processing are shown in Table III. At first, the distribution of heats among steel groups was determined, as presented in Figure 2.

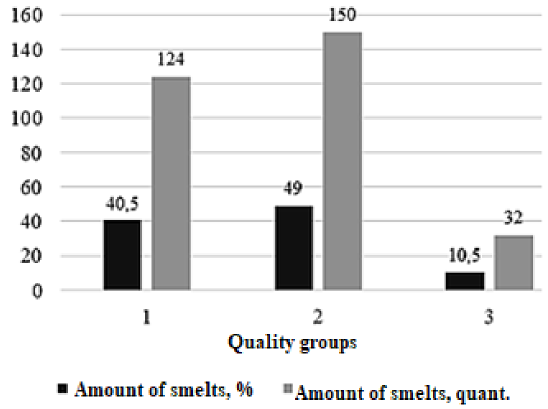

Fig. 2. Distribution of heats by metal group.

TABLE III. RESULTS OF STATISTICAL PROCESSING OF 306 HEATS

Var.	Statistics results						
	No. of metal melts	Average	Minimum	Maximum	Dispersion	Avg. sq. dev.	Coef. of variations V, %
T_{cast}, °C	305	1468.049	1443.000	1480.00	62.475	7.90408	0.5384
C, %	306	1.217	1.124	1.300	0.001	0.02972	2.4416
Mn, %	306	13.312	10.820	15.220	0.594	0.77039	5.7870
Si, %	306	0.519	0.250	0.767	0.005	0.07195	13.8521
P, %	306	0.032	0.003	0.049	0.000	0.00512	16.2647
S, %	305	0.005	0.002	0.100	0.000	0.00572	119.3194
Cr, %	306	0.113	0.070	0.180	0,000	0.01768	15.5772
Al, %	304	0.007	0.001	0.020	0.000	0.00351	48.6604
Ni, %	306	0.063	0.039	0.156	0.000	0.01076	17.0065
Cu, %	306	0.081	0.052	0.124	0.000	0.01030	12.7974
V, %	306	0.021	0.009	0.029	0.000	0.00356	16.8995
Mo, %	302	0.037	0.011	0.277	0.000	0.01882	51.5543
W, %	109	0.023	0.010	0.064	0.000	0.01202	52.9089
FeO, %	303	1.409	0.450	3.140	0.151	0.38811	27.5528
MnO, %	303	10.75	2.520	19.080	5.900	2.4291	22.57
σ_T, MPa	306	876.70	710.00	1010.00	3932.5	62.7096	7.1529
σ_y, MPa	306	418.84	305.00	535.00	940.4	30.6655	7.3215
δ, %	306	50.124	30.000	74.000	73.860	8.59418	17.1458
Ψ, %	306	33.536	25.000	56.000	13.915	3.73029	11.1233
KCU, J/sm^2	306	29.151	19.800	37.000	7.888	2.80864	9.d6349

As can be seen from the histogram of the metal groups, after the introduction of the proposed innovations, the number of melts of the first group amounted to 124 pieces or 40.5%. This is significantly higher than the previous implementation (28.9%), indicating the effectiveness of three directions to improve 110G13L melting. At the same time, the number of heats in group 1 must be increased. To do this, the statistical results were analyzed.

The data in Table III indicate that the average values of σ_T, δ, φ and K_S are equal to 418.84 MPa, 50.12%, 33.53%, and 29.15 J/cm^2 for the first group of metal, and only the average value σ_B of 876.70 kgf/mm^2 corresponds to group 2. Therefore, increased attention was paid to this indicator by studying the σ_B histogram of the mechanical properties of steel presented in Figure 3.

As can be seen in the histogram, the number of melts σ_B corresponding to the first group of metal, that is >900 MPa, is equal to 121 pieces or 39.5%. This indicator closely correlates with the number of heats of the first group (Figure 2). This indicates that metal groups are mainly determined by the achieved tensile strength values. Therefore, the main task of further research was to find ways to increase and stabilize this indicator. To identify all the factors influencing the σ_B of the melted steel, a regression analysis was performed on the dependence of this indicator on the chemical composition of steel and slag, as well as the melt pouring temperature. Stepwise regression was used, excluding independent variables from dependent, one at each step until the final goal was achieved only with the variables that are most significant for regression. Table IV shows the stepwise regression results.

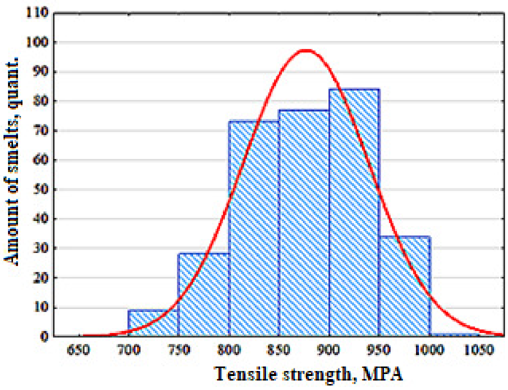

Fig. 3. Histogram of tensile strength.

TABLE IV. RESULTS OF STATISTICAL PROCESSING OF 306 HEATS

	Standard grade	**Avg. sq. st.dev. estimates**	**Regression coef.**	**Average sq.dev. regression coef.**	**t - criterion**	***p*-level importance regression coef.**
Free term			-92.8272	48.41074	-1.91749	0.056161
Mn, %	**0.707880**	**0.040944**	**5.7731**	**0.33391**	**17.28913**	**0.000000**
Mo, %	0.091620	0.041472	30.4326	13.77537	2.20920	0.027945
Si, %	-0.095633	0.041208	-8.4243	3.62997	-2.32076	0.020996
T cast,	0.092365	0.041282	0.0737	0.03293	2.23743	0.026020
FeO, %	-0.057213	0.041202	-0.9224	0.66427	-1.38862	0.166018

The regression equation has the form:

$$\sigma_B = -92.82 + 0.0737T_{cast} + 5.7731Mn - 8{,}42Si - 0.924FeO + 30.43Mo$$

Negative values of the coefficients for variables indicate the need to reduce them in steel to increase σ_B. Positive values of the coefficients for variables indicate, on the contrary, the need to increase them in steel to increase σ_B. Thus, in the melt, first of all it is necessary to increase the concentration of manganese, the pouring temperature, and reduce the content of silicon and iron oxide in the slag**.** The data in Table IV show that impurities in steel within the limits introduced into the melt by charge materials do not have a significant effect on σ_B. Only molybdenum has a positive effect. Thus, it can be concluded that the charge materials used at the plant are of satisfactory quality and provide the required mechanical properties and quality grades of the steel produced.

The data in Table IV show that the concentration of manganese in the melt has the most significant effect on σ_B since the significance of the coefficient for the manganese variable (*p*) is 5 orders of magnitude lower than the accepted statistical significance level of 0.05. In second place, in terms of the degree of influence on σ_B, is the silicon content (*p*=0.020996), and then follows the pouring temperature (p = 0.026). The FeO content in the slag is also important (p = 0.166, which is close to 0.05). The remaining variables within the concentrations achieved at the plant by steelmakers have virtually no effect on tensile strength. To further increase the number of melts corresponding to the first group, it is necessary to increase the manganese concentration in the metal to 14% and higher and maintain the silicon content in an amount sufficient for deoxidation (<0.6%). It is important to improve the technology of diffusion deoxidation. For this purpose, it is proposed to use burned lump lime instead of carbonate rock during the recovery period of the smelting. In this case, no time and energy consumption will be required for the dissociation of carbonates, reducing material consumption and labor intensity. This will significantly reduce the smelting recovery period and energy consumption. The slags will build up easier and faster and will be more reactive, and the mechanical properties of steel will increase.

Based on the results of statistical and regression analyses, 63 heats were performed considering the recommendations developed. The results of statistical processing showed that the manganese concentration in steel increased on average from 13.3 to 14.5%, that is, by 8.7%. The replacement of carbonate rock with burned lump lime led to a halving of its consumption from 200 to 100 kg, a reduction in the intensity of steelworker labor during the recovery period of smelting and energy consumption. The slags turned out to be highly basic and reactive. FeO concentrations in the slag decreased on average from 1.4 to 1.3% (6.9%). The MnO content in the slag decreased significantly from 10.7 to 7.5% (29.6%). As a result, the number of heats of the first group increased to 71%.

This work also included a technical and economic assessment of the developed technological solutions. A comparative assessment was made according to the following criteria: reduction of production costs and increase in production efficiency, and improvement of operational characteristics and quality of the obtained castings.

The introduction of innovative methods for processing 110G13L steel made it possible to reduce production costs by reducing the consumption of slag-forming materials from 200 to 100 kg, reducing energy costs due to a reduction in the time of charge melting by 10 minutes, and reducing the labor intensity of steelmakers. Calculations showed a reduction in the cost of producing one ton of steel by 16.92 euros.

Evaluation of operational characteristics and quality of the obtained castings showed that the number of heats corresponding to the first quality group according to GOST 7370 increased from 29% to 71% due to an increase in the mechanical properties of steel. This indicates a significant improvement in the quality of manufactured products, increasing their competitiveness in the market and meeting the growing requirements for the reliability of railway castings. Improving the quality of steel and increasing the share of heats of the first quality group directly affect the durability and reliability of railway castings, increasing the service life of parts and, accordingly, the costs of servicing the railway infrastructure for consumers.

IV. CONCLUSION

The study proposed a new comprehensive method to improve the quality of 110G13L steel based on the combined effect of innovative diffusion deoxidizers on the metal. The implementation of three areas of improvement in the technological process of melting 110G13L for critical railway castings due to the complex effect on the metal when using innovative diffusion deoxidizers when organizing early slag formation during melting of the charge, increasing the efficiency of diffusion deoxidation of steel due to the use of a DAD, extra-furnace treatment of the melt in a ladle using a URM that provides an adsorption-flotation method of refining steel in combination with optimization of the chemical composition of steel and slag, made it possible to sharply improve the mechanical properties of steels and increase the number of melts of the first group according to GOST 7370 from 29 to 71%.

This indicates a significant improvement in the quality of manufactured products, which in turn has a positive effect on the reliability and durability of railway castings. Optimization of the chemical composition of steel and slag contributed to the improvement of the metal structure, increasing its strength, wear resistance, and other performance characteristics. Therefore, the measures taken not only increased the efficiency of the technological process but also ensured that the products met stricter quality standards, which is important to ensure the safety and reliability of rail transport.

The economic effect of the implementation was 16.92 euros per ton of steel produced due to a reduction in the consumption of slag-forming materials, a reduction in energy costs due to a reduction in the time of melting the charge in the furnace, and a reduction in the labor intensity of the steelmakers.

REFERENCES

[1] D. A. Mazinsky, "Hadfield steel and its exceptional place in metallurgy", in *Results of applied and exploratory scientific research in the field of natural science and technology: Collection of scientific papers based on the materials of the International Scientific and Practical Conference*, Belgorod, Russia: LLC Agency for Advanced Scientific Research (APNI), 2019, pp. 90-93.

[2] N. G. Davydov, S. V. Shitnov, and S. G. Bratchikov, "High Manganese Steel", *Metallurgy*, 1995, Art. no. 302.

[3] J. E. Bringas, Hand Book of Comparative World Steel Standard s. ASTM International, 2004.

[4] S. Kusunoki, R. Nishihara, K. Kato, H. Sakagami, S. F. N. Hirashima, and N. Fukunaga, "Development of steelmaking processes for producing various high-quality steel grades at yawata works," 2013. [Online]. Available: https://www.nipponsteel.com/en/tech/report/nsc/pdf/104-18.pdf.

[5] *Steel castings. General specifications*. GOST 977-88, Standards Publishing House, Russia, 1988.

[6] *Railway crosspieces. Technical specifications.* GOST 7370-2015, Standards Publishing House, Russia, 2015.

[7] N. Vasilyeva, E. Fedorova, and A. Kolesnikov, "Big Data as a Tool for Building a Predictive Model of Mill Roll Wear," *Symmetry*, vol. 13, no. 5, May 2021, Art. no. 859, https://doi.org/10.3390/sym13050859.

[8] A. S. Kolesnikov, "Kinetic investigations into the distillation of nonferrous metals during complex processing of waste of metallurgical industry," *Russian Journal of Non-Ferrous Metals*, vol. 56, no. 1, pp. 1–5, Jan. 2015, https://doi.org/10.3103/S1067821215010113.

[9] I. Volokitina *et al.*, "Study of changes in microstructure and metal interface Cu/Al during bimetallic construction wire straining," *Case Studies in Construction Materials*, vol. 18, Jul. 2023, Art. no. e02162, https://doi.org/10.1016/j.cscm.2023.e02162.

[10] I. Volokitina, E. Siziakova, R. Fediuk, and A. Kolesnikov, "Development of a Thermomechanical Treatment Mode for Stainless-Steel Rings," *Materials*, vol. 15, no. 14, Jul. 2022, Art. no. 4930, https://doi.org/10.3390/ma15144930.

[11] N. Zhangabay *et al.*, "Factors affecting extended avalanche destructions on long-distance gas pipe lines: Review," *Case Studies in Construction Materials*, vol. 19, Dec. 2023, Art. no. e02376, https://doi.org/10.1016/j.cscm.2023.e02376.

[12] I. I. Eliseeva, N. A. Flud, and M. M. Yuzbashev, "Workshop on the general theory of statistics: textbook," in *Finance and Statistics*, 2008.

[13] V. N. Salin, E. Y. Churilova, and E. P. Shpakovskaya, *Statistics: textbook*, KNORUS, 2007.

[14] N. M. Mulyavko, "Analysis of the operational resistance of castings made of steel 110G13L," *News of the Chelyabinsk Scientific Center*, vol. 4, no. 13, pp 28-30, 2001.

[15] D. Deleg and N. Khash-Ochir, "Requirements for using deferent types of the bucret teeth of excavator," presented at The 4th International Conference on Creative Science and Technology, Mongolia, Oct. 2013.

[16] M. R. Efimova, O. I. Gachenko, and E. V. Petrova, *Workshop on the general theory of statistics: Textbook*, Finance and Statistics, 2002.

[17] D. A. Tsurkan, "Control of the structure and properties of steels 110G13L, 38XC, 45XH, used for the manufacture of parts for special machines", Ph.D. dissertation, Altai State Technical University, Barnaul, Russia, 2012.

[18] I. P. Egamberdiev, L. Atakulov, R. O. Muminov, and K. K. Ashurov, "Research of vibration processes of bearing units of mining equipment," *International Journal of Advanced Trends in Computer Science and Engineering*, vol. 9, no. 5, pp. 7789–7793, 2020.

[19] I. P. Egamberdiev, "Spectral analysis of the oscillatory process of support assemblies on drilling machines," *International Journal of Advanced Research in Science, Engineering and Technology*, vol. 5, no. 5, 2018, Art. no. 5958.

[20] N. I. Gabelchenko, Y. V. Grebnev, N. V. Volkova, and A. A. Zenin, "Obtaining a homogeneous austenitic structure in castings from steel 110G13L", *Problems of materials science, welding and strength in mechanical engineering,* vol. 4, pp. 151-154, 2010.

[21] N. I. Gabelchenko, O. A. Mishustin, and S. B. Khantimirova, "Improving the quality of castings from steel 110G13L by optimizing the heat treatment regime," *Techniques, Technologies, Engineering*, vol. 1, no. 7. pp. 21-24, 2018.

[22] A. M. Sysoev, V. V. Bakhmet'ev, and V. M. Kolokol'tsev, "Refining and modifying of 110G13L steel by titanium-boron-calcium complex," *Vestnik Magnitogorskogo Gosudarstvennogo Tekhnicheskogo Universiteta Im. GI Nosova*, no. 1, pp. 43–45, 2008.

[23] D. A. Tsurkan, A. N. Leontyev, and A. V. Ishkov, "Increasing the structural strength of 110G13L steel and cast parts used in special machines by alloying Mo, Ni and modifying rare-earth metals," *Polzunovsky Bulletin*, no. 1, pp. 43-45, 2008.

[24] S. R. Seydametov, N. K. Tursunov, and S. P. Alimukhamedov, "Development of out-of-furnace steel treatment technology for the manufacture of railroad transport parts," *AIP Conference Proceedings*, vol. 3045, no. 1, Mar. 2024, Art. no. 060022, https://doi.org/10.1063/5.0197429.

[25] T. Urazbayev, N. Tursunov, and T. Tursunov, "Steel modification modes for improving the cast parts quality of the rolling stock couplers," *AIP Conference Proceedings*, vol. 3045, no. 1, Mar. 2024, Art. no. 060015, https://doi.org/10.1063/5.0197361.

[26] N. K. Tursunov, A. E. Semin, and E. A. Sanokulov, "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*, vol. 1, pp. 33–40, 2017.

[27] A. V. Chaikin, V. A. Chaikin, A. D. Kasimgazinov, and P. O. Bykov, "New material for diffusion deoxidation in a complex steel processing unit," *Ferrous Metals*, no. 9, pp. 6-11, 2018.

[28] A. V. Chaikin, V. A. Chaikin, V. V. Kolpakov, and K. N. Vdovin, "Introduction of innovations in steel smelting for critical castings of freight car bogies in order to increase their operational reliability," *Ferrous Metals*, no. 9, pp. 9-13, 2021.

[29] F. Boursas, R. Boufarh, and B. Maghaghi, "The Influence of Slenderness in Steel and Composite Columns under Fire Conditions," *Engineering, Technology & Applied Science Research*, vol. 13, no. 1, pp. 10145–10150, Feb. 2023, https://doi.org/10.48084/etasr.5560.

[30] P. O. Bykov, M. Zh. Tussupbekova, and D. R. Absolyamova, "Research of the Process of Production of Steel Square Continuous Billets for Rolling Balls of Large Diameter," *Defect and Diffusion Forum*, vol. 410, pp. 330–335, Aug. 2021, https://doi.org/10.4028/www.scientific.net/DDF.410.330.

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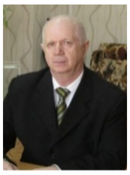

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