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Research of the Process of Production of Steel Square Continuous Billets for Rolling Balls of Large Diameter

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Abstract. The paper investigates the technology of production of steel billets continuously cast billets for rolling balls of large diameter. In Kazakhstan, in connection with the development of new copper deposits such as Aktogay and Bozshakol, the need for large diameter steel grinding balls for primary ore processing has increased. The main problem in the operation of large diameter grinding balls is the tendency of the grinding media to break during operation. The authors of the work investigated the process of production of steel billets continuously cast billets with a cross section of 150 × 150 mm for rolling balls of large diameter (d 125 mm) in the PB LLP "KSP Steel", which showed that the breaking of grinding balls is initiated mainly by the presence of internal discontinuities (gas axial looseness) in continuously cast billets. Studies have shown that the technological scheme for the production of grinding balls with a diameter of 125 mm from continuously cast billets with a section of 150 × 150 mm, including steel smelting in an arc furnace with steel finishing on a ladle-furnace unit, deoxidation with aluminum and degassing in a ladle vacuum apparatus, casting steel in a closed jet on a continuous casting and further production of rolled stock on a rough rolling mill ensures the absence of internal discontinuities (gas bubbles, axial looseness) in the workpieces and ensures the production of high quality balls.

Introduction

In Kazakhstan, in connection with the development of new copper deposits such as the Aktogay deposit and the Bozshakol deposit, the need for large-diameter grinding balls for primary ore processing has increased [1 - 3]. Grinding balls of normal and high hardness are usually used in ball mills for grinding relatively soft materials (ore, coal and some building materials) [4, 5]. During operation, steel grinding balls experience periodic shock loads that can lead to their destruction. In this regard, they must have the following properties: high hardness and strength, increased resistance to abrasion and corrosion, retention of the shape of the metal ball with its uniform wear, resistance to cracking and coloration, dense ball structure without metallurgical defects. The main problem in the operation of large-diameter grinding balls is the tendency of grinding bodies to fracture [6 - 8]. The reasons for the development of cracks in large-diameter grinding balls are defects of metallurgical origin of non-continuously cast billets with a small cross-section (shrinkage and gas porosity), which are not completely eliminated during rolling due to the low degree of reduction and structure elaboration [9 - 20]. Thus, solving the issue of reducing the degree of development of shrinkage and gas porosity in continuously cast steel billets of small cross-section will improve the quality of rolled grinding balls of large diameter.

Field Study and Results

The authors of the work investigated the technology of production of steel billets continuously cast billets with a section of 150 × 150 mm for rolling balls with a diameter of 125 mm. Requirements for the chemical composition of steel are given in Table 1.

Steel smelting was carried out in electric arc steel-making furnaces (EAF) with a volume of 60 tons in a single-slag process, with further processing on a ladle furnace unit with aluminum or silicocalcium with further degassing in a ladle vacuum apparatus at a residual pressure of 1.33 mbar. Refining in a ladle vacuum apparatus pursued the goal of maximum removal of dissolved gases of steel. Steel casting was made on a radial continuous casting machine (CCM) with a radius of 10 meters under the level or with an open stream in a mold.

Table 1. Requirements for the chemical composition of steel, %

	C	Si	Mn	P	S	Cr	Ni	Cu
min	0.57	0.25	0.75	-	-	0.20	-	-
max	0.63	0.32	0.90	0.025	0.025	0.30	0.2	0.2

Scrap metal of categories 1A, 2A was used as charge materials, waste of the processing sections according to GOST 2787. For carburizing the metal, a carbon-containing material with a fraction of 0.5-5 mm with a carbon content of at least 93% was used. Freshly burnt lime with a content of active oxides CaO + MgO of at least 80%, fluorspar according to GOST 29220-91 was used as slag-forming ones.

For deoxidation, alloying and modification of steel, ferrosilicon manganese according to GOST 4756-91 (FeMnSi), ferrosilicon according to GOST 1415-93 (FeSi 65), silicocalcium according to GOST 4762-71 (SK30), ferromanganese according to GOST 4755-91, aluminum AB-87, AV-97 GOST 295-98 Aluminum wire rod GOST 13843-78.

After casting the steel, templates of continuously cast billets were taken from each strand of the continuous casting machine in the middle of each heat to determine the defects of the macrostructure according to the requirements of STO 002-2014.

The macrostructure of the workpiece must meet the following requirements:

- central porosity (CP) - no more than 3 points;
- axial chemical heterogeneity (ACH) - no more than 3 points;
- liquation stripes and cracks (LSC) - no more than 2 points;
- edge point pollution (EPP) - no more than 2 points;
- subcrustal gas bubble (GWP) - not allowed.

The work carried out a statistical analysis of the reasons for the formation of the "gas bubble" defect.

The sample was made for 50 heats, including heats with a "gas bubble" defect and heats without this defect. The following technological factors were considered:

- thermal and energy indicators (general, specific);
- chemical composition of swimming trunks (C, S, P, Cu);
- parameters of casting on a continuous casting machine;
- temperature conditions of steel casting;
- technological modes of production of rolled stock (compression of continuous casting machine).

Table 2 presents an analysis of the macrostructure of the continuous casting machine cast on the continuous casting machine-2 (closed jet) in 2017.

Table 2. Macrostructure of a continuously cast billet with a section of 150 × 150 mm (2017)

Smelting No.	№ R	№ billets	Macrostructure analysis, score					Note (not allowed)
			CP, no more than 3 [points]	ACH, no more than 3 [points]	LSC		EPP, no more than 2 [points]	
					cross section, no more than 2 [points]	axial, no more than 2 [points]		
6161033	1	17	0	1	1	0	0.5	
	2	16	3	1	0.5	1	0.5	
	3	22	0	1.5	0.5	0.5	0.5	
6161034	1	16	1	1.5	1	1	0.5	
	2	17	3	2.5	1	1	0.5	

Smelting No.			Macrostructure analysis, score					Note (not allowed)
	№ R	№ billets	CP, no more than 3 [points]	ACH, no more than 3 [points]	LSC cross section, no more than 2 [points]	LSC axial, no more than 2 [points]	EPP, no more than 2 [points]	
	3	15	2	1	1	1	1	
6161035	1	16	0	2.5	1	1	1.5	
	2	17	0	2.5	1	1	1.5	
	3	15	0	1.5	1	0	1	
6161036	1	16	1	2	1	0	0.5	
	2	17	0	1,5	0.5	0	0.5	
	3	15	0	1	0.5	0.5	0.5	
6161037	1	11	0	1.5	0.5	0	0.5	
	2	12	0	1	0.5	0	0.5	
	3	13	0	1.5	0	0	1	GWP 5 [mm]
6161038	1	15	0	1	0.5	0	1	
	2	16	0	1.5	0.5	0.5	0.5	
	3	14	0	2	0.5	0	1.5	

As can be seen from table 2, template No. 1 includes a gas bubble with a depth of 5 mm.

Table 3 presents an analysis of the macrostructure of a square continuous casting machine during the transition of casting CCM-1 (open stream) in 2018.

Table 3. Macrostructure of a continuously cast billet with a section of 150 × 150 mm (2018)

Smelting No.			Macrostructure analysis, [score]					Note (not allowed)
	№ R	№ billets	CP, no more than 3 [points]	ACH, no more than 3 [points]	LSC cross section, no more than 2 [points]	LSC axial, no more than 2 [points]	EPP, no more than 2 [points]	
5171653	1	16	2	1	2	0.5	2	
	2	17	0	1.5	1.5	1	2	
6172782	1	14	2	2	1	0.5	2.5	
	1	12	3	2	0	0	2	
	2	15	3	2	0.5	0.5	3	GWP 7 [mm]
	2	13	0	2	0.5	0	3	GWP till 9 [mm]
5171758	1	12	0	1.5	0.5	0.5	1.5	
	2	13	2	1.5	1	0.5	2	
5171776	2	13	2	2	0	0.5	0.5	GWP 8 [mm]
	2	13	3	1.5	0.5	0	1	GWP 11 [mm]
	2	17	3	1.5	0	0.5	1	GWP 8 [mm]
	3	14	3	1.5	1	0.5	3	
	3	16	0	10.5	0.5	0.5		GWP 6 [mm]
5171774/1	2	13	0	2.5	0	0	1	

Smelting No.	№ R	№ billets	Macrostructure analysis, [score]					Note (not allowed)
			CP, no more than 3 [points]	ACH, no more than 3 [points]	LSC cross section, no more than 2 [points]	LSC axial, no more than 2 [points]	EPP, no more than 2 [points]	
	3	14	0	1.5	0.5	1	0.5	GWP 7 [mm]
	3	14	2	1	0.5	0	2	GWP 5 [mm]
	3	12	3	2	1	1	2	GWP 3 [mm]
5171778	1	12	2	1.5	0.5	0.5	2	
	3	13	3	2	1	0.5	3	
	3	15	3	1	0	0	2	GWP 7 [mm]
5171775	3	13	0	1.5	0.5	0.5	0.5	
	1	14	0	1.5	0	0.5	0.5	

As can be seen from Table 3, 68.71% of the studied templates from this series of heats include a gas bubble with a depth of 3 to 11 mm.

Macrostructure of billets from a series of heats cast on continuous casting machine-2 (closed stream) in 2019 is presented in Table 4.

Table 4. Macrostructure of a continuously cast billet with a section of 150 × 150 mm (2019)

Smelting No.	№ R	№ of billets	Macrostructure analysis, score					Note (not allowed)
			CP, no more than 3 points	ACH, no more than 3 points	LSC cross section, no more than 2 points	LSC axial, no more than 2 points	EPP, no more than 2 points	
6180040	1	12	0	2	1	0	1	
	2	11	0	1.5	1	1.5	1.5	
	3	10	0	2.5	0.5	0.5	0.5	
6180041	1	11	2	1	0.5	0.5	2	
	2	13	1	1.5	1	0.5	1.5	
	3	12	0	1.5	0.5	0	2	
6180042	1	10	0	1	0.5	0	1	
	2	12	0	1.5	0.5	0	1	
	3	11	2	1.5	0.5	0.5	1	
6180043	1	11	2	1.5	0.5	0	1.5	
	2	10	3	2	1	0.5	1	
6180044	1	12	2	1.5	0.5	1	1.5	
	2	11	0	2	1	1,5	1.5	
6180045	1	10	0	1	1	0.5	2	
	2	12	3	1.5	0.5	1	1.5	
	3	11	3	2	1	0.5	2	
6180046	1	12	1	2	1.5	0.5	1.5	
	2	11	2	1	1	0.5	1	
	3	10	0	1.5	0.5	0	1.5	

There is no gas bubble in the macrostructure of those casts in 2019.

The Discussion of the Results

Analyzing the above indicators for smelting, casting and studying the macrostructure of continuous cast billets for the production of large diameter rolled balls (125 mm), the following conclusions can be drawn:

1) When smelting steel for closed-jet casting on a continuous casting machine No. 2 with steel deoxidation with aluminum additives and degassing in a ladle vacuum, for a more complete removal of oxygen from the melt, the macrostructure of the blanks in terms of central porosity, axial chemical heterogeneity, segregation stripes and cracks, edge point pollution and the absence of subcrustal gas bubbles (table 4).

In this case, the casting speed must be maintained according to the lower limit established in the production flow chart for a given steel grade.

2) When smelting steel for open-stream casting on a continuous casting machine No. 1 with steel deoxidation with silicocalcium instead of aluminum and degassing in a ladle vacuum apparatus for a more complete oxygen removal, in general, it ensures that the macrostructure of the blanks corresponds to the central porosity, axial chemical heterogeneity, segregation stripes and cracks , edge point pollution in the presence of subcrustal gas bubbles in 68.71% of the studied blanks (table 3).

3) Based on the studies carried out, it can be concluded that the optimal steel production scheme for the production of large-diameter rolled balls (125 mm) from continuously cast billets with a cross-section of 150 × 150 mm is: out-of-furnace treatment at the ladle-furnace unit with aluminum deoxidation and subsequent degassing in a ladle vacuum apparatus further casting with a closed stream.

Conclusions

1) According to the results of industrial tests and statistical analysis, the influence of the macrostructure of steel continuously cast billets with a cross section of 150 × 150 mm on the tendency of rolled balls of large diameter (125 mm) to fracture during operation was revealed due to the presence of internal discontinuities (gas bubbles, axial looseness) in the billets.

2) A technological scheme for the production of continuously cast billets with a cross section of 150 × 150 mm for the production of rolled balls of large diameter (125 mm) has been developed and experimentally confirmed, including steel smelting in an arc furnace and finishing of steel on a ladle-furnace unit with aluminum deoxidation, degassing in a ladle vacuum apparatus and closed stream casting on a continuous billet casting machine, which ensures compliance with the macrostructure of the billets in terms of central porosity, axial chemical heterogeneity, liquation stripes and cracks, edge point contamination and the absence of subcrustal gas bubbles.

References

[1] P. Shen, H. Pan, E. Seitmuratova, F. Yuan, S. Jakupova, A Cambrian intra-oceanic subduction system in the Bozshakol area, Kazakhsten, Lithos. 224-225 (2015) 61-77.

[2] B.R. Rakishev, New large open pit copper mines in Kazakhstan, Mining Informational and Analytical Bulletin. 4 (2018) 5-14.

[3] B.R. Rakishev, Development of the Bozshakol and Aktogay copper ore deposits in Kazakhstan, Gornyi Zhurnal. 1 (2019) 89-92.

[4] Z. Wentao, H. Yuexin, L. Yanjun, M. Shaojian, S. Yongsheng, Research on prediction model of ore grinding particle size distribution, Journal of Dispersion Science and Technology. 41(4) (2020) 537-546.

[5] A. Abazarpoor, R. Hejazi, M. Saghaeian, V. Sheikhzadeh, Ball mill and HPGR effect on the particle size, shape and specific surface area of pellet feed, IMPC 2018 - 29th International Mineral Processing Congress, 2019, pp. 390-399.

[6] N.A. Shaburova, Studying the peculiarities of steel grinding balls structuring, Solid State Phenomena. 284 (2018) 685-689.

[7] K.N. Shvedov, I.K. Galim'yanov, M.A. Kazakovtsev, Production of grinding balls of high surface and normalized volume hardness, Metallurgist. 64(5-6) (2020) 499-507.

[8] D.V. Stalinskii, A.S. Rudyuk, V.K. Solenyi, grinding balls for the first stage of iron raw grinding in tumbling mills, Steel in Translation. 50(2) (2020) 116-127.

[9] S.S. Spanov, A.K. Zhunusov, L.B. Tolymbekova, Pilot plant melting of steel using Ferro-Silico-Aluminum at KSP steel, Metallurgist. 60(11-12) (2017) 1149-1154.

[10] A.T. Kanaev, P.O. Bykov, A.V. Bogomolov, E.N. Reshotkina, Reducing the central porosity of continuous-cast billet by modification of the solidification process, Steel in Translation. 42(8) (2012) 643-645.

[11] E.N. Smirnov, A.N. Smirnov, V.A. Sklyar, V.A. Belevitin, S.V. Kuberskii, Technical feasibility assessment for roll pass designs in three-high shape-mill stands in modern mini-mills, Metallurgist. 63(11-12) (2020) 1294-1302.

[12] R. Pyszko, M. Príhoda, M. Machu, Z. Franek, Data processing of measured surface temperatures of continuously cast billets and blooms to verify the numerical solidification model, 29th International Conference on Metallurgy and Materials, Brno, Czech Republic, 2020, pp. 80-85.

[13] V.V. Naumenko, A.V. Muntin, A.V. Danilenko, O.A. Baranova, study of the surface defect nature of hot-rolled products in the edge zone, Steel in Translation. 50(1) (2020) 46-52.

[14] V. Solanki, G. Mukhopadhyay, Metallurgical analysis of transverse crack of rebars, Engineering Failure Analysis. 104 (2019) 1143-1156.

[15] K.N. Vdovin, V.V. Tochilkin, O.A. Filatova, V.V. Tochilkin, Analysis of the process of casting of the metal by an open stream and the design of the equipment of receiving chambers of the Tundish of CCM, Refractories and Industrial Ceramics. 60(1) (2019) 6-9.

[16] M.Y. Chubukov, D.V. Rutskiy, D.P. Uskov, Analyzing the features of non-metallic inclusion distribution in Ø410 mm continuously cast billets of low carbon steel grades, Materials Science Forum. 973 (2019) 21-25.

[17] A.A. Umanskii, L.V. Dumova, influence of electrosmelting conditions on rail quality and production costs, Steel in Translation. 48(11) (2018) 712-717.

[18] J. Sviželová, M. Tkadlečková, K. Michalek, M. Strouhalová, Influence of casting speed on centerline porosity formation in continuously cast round steel billets, 26th International Conference on Metallurgy and Materials, Hotel Voronez I, Brno, Czech Republic, 2017, pp. 235-240.

[19] I. Clitan, M. Abrudean, V. Muresan, D. Sas, Optimizing the casting length of single diameter steel billets based on minimum cost, 2016 20th International Conference on System Theory, Control and Computing (ICSTCC), Sinaia, Romania, 2016, pp. 73-78.

[20] Y.N. Smyrnov, V.A. Skliar, V.A. Belevitin, R.A. Shmyglya, O.Y. Smyrnov, Defect healing in the axial zone of continuous-cast billet, Steel in Translation. 46(5) (2016) 325-328.