Issue VI, 22 November 2023
e-ISSN 2707-9481 Institute of Metallurgy and Ore Beneficiation, Satbayev University, Almaty, Kazakhstan
ISBN 978-601-323-356-7 https://doi.org/10.31643/2023.21

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About economic efficiency of electroslag refining process of iron-rich raw material

Abstract: The question of efficiency of use of metalized pellets for production of consumable electrodes subjected to electroslag remelting process in order to obtain metal pure in phosphorus and impurities of non-ferrous metals is considered. Analytical estimation of the processes occurring during the interaction "pellet - ligature" has been made, which allowed to obtain optimal parameters for the formation of consumable electrode from ligature and metallized pellets. The experimental estimation of temperature interval of pellets preheating 300...500 °C was carried out. The optimum temperature of pellets preheating is determined, which is 400 °C. The obtained prototypes are investigated and it is established that pellet preheating up to 400 °C allows to obtain fusion of pellet surface layers with ligature. The technology of formation of expendable electrodes from metalized pellets by pouring liquid ligature into a special liner with a polystyrene rod pre-installed in it has been developed.
Keywords: iron, raw material, slag, refining process, costs of production.

Cite this article as: Chumanov I., Anikeev A., Sergeev D. (2023). About economic efficiency of electroslag refining process of iron-rich raw material. *Challenges of Science*. Issue VI, 2023, pp. 180-183. https://doi.org/10.31643/2023.21

Introduction

At present, considerable experience has been accumulated in the direct production of iron and its use in steelmaking, bypassing the blast furnace process. The increased interest in the products of direct reduction is explained by their guaranteed purity in terms of the content of impurities of non-ferrous metals, as well as sulfur and phosphorus, which allows to significantly reduce the duration of the refining period of melting and increase the mechanical characteristics of steel (Lyalyuk et al., 2018; Zhunussova et al., 2023).

More than 75% of reduced iron is smelted in electric furnaces. Continuous loading of metalized pellets, which are more transportable than scrap, into the furnace allows to significantly increase the productivity of electric furnaces. This is achieved due to the absence of time losses for pelletizing and increased transformer power utilization due to high stable power consumption. However, the conventional methods do not allow to fully utilize the advantages of pure virgin pellets.

The costs of production of metalized raw materials significantly exceed the costs of scrap metal (3...8 times). Therefore, more than 60% of the cost of metal in the structure of metal production cost is metalized pellets. Costs are reduced as a result of increased production of metalized pellets when the entire complex of shaft furnaces is put into commercial operation and the technology of their production is fully mastered at the Oskol Electrometallurgical Plant (OEMP).

Currently, this method has been tested and implemented on an experimental industrial scale at some machine-building plants, where ingots weighing up to 650 kg of die and roll steel are produced. The melting technology includes continuous supply of all necessary components to the mold, extraction of ingot from the mold in the course of melting and drainage of excess slag (Nikitchenko et al., 2018).

The presence of iron oxides in slag, metal contact with furnace lining during the smelting process and with the air atmosphere during discharge and casting, introduction of deoxidizers leads to contamination of steel with non-metallic inclusions and gases. Increasing the purity of metal through the use of synthetic slags and vacuumization, as well as the use of refining remelting significantly increase the cost of steel (Kerimov & Shakhov, 2020).

In this regard, studies on the development of new processes for steel production by one-stage transformation of direct iron reduction products into homogeneous ingots are of particular interest (Puzakov et al., 2020). Such technologies are casting on continuous casting machines and in special molds, which allow to obtain electrodes with a good surface and less shrinkage.

Research Method

Economic efficiency of mastering the process of electroslag remelting of metallized raw materials is determined by comparing current, specific capital and reduced costs for the production of rolling rolls on the compared variants of technology from tool alloy steel type 60Х2СМФ for rolls of cold rolling mills in the conditions of OEMP.

Industrial development of the new technology of production of rolling rolls from ESSP metal in comparison with ESSP in the conditions of metallurgical production provides cost savings in the field of metallurgical production. This is due to the 10 - 15% excess of cost savings on technological operations excluded from the technological scheme of production (operations for the manufacture of consumable electrodes) (Bersenev et al., 2018).

Metalized pellets are one of the varieties of sponge iron, which is a product of direct reduction of iron carried out in the solid phase. Sponge iron pellets are distinguished from other types of sponge iron by the spherical shape of the particles, which is inherited from the raw material used - iron ore pellets. If chunks of rich iron ore are used as raw material, the end product of direct reduction will be lumpy sponge iron. In a number of processes, powdered iron ore concentrates are used as raw materials.

At present, economical processes of direct reduction of iron, which allow using solid fuel cheaper than natural gas, are being widely developed all over the world. Works on direct reduction of iron with gasification of hard coal and subsequent gas reduction of iron are underway. Much attention is paid to liquid-phase direct reduction processes, which provide for production of relatively small portions of pig iron using cheap small lump ore and low-grade coals as raw materials, including non-coking coals.

Одним из главных показателей качества металлизованных окатышей является степень One of the main indicators of the quality of metallized pellets is the degree of metallization, i.e. the ratio of metallic iron content to the total iron content. Pellets suitable for processing into steel should have a metallization degree of 85...97%.

The phosphorus content in metallized pellets is usually in the range of 0.010...0.030 %, and sulfur - 0.030...0.070 % (when using solid reducing agents, the sulfur content can be much higher) (Titov, 2018).

Metalized pellets are used for steelmaking in electric arc furnaces, as well as (very limitedly) for steelmaking in oxygen converters and low-frequency induction furnaces. Electric arc smelting accounts for the bulk of steels smelted using metallized pellets. The content of pellets in the charge is 50 % and more, while in oxygen converter smelting this indicator does not exceed 25...30 %. The quality of mass consumption steels produced using metalized pellets in electric arc furnace, converter or induction furnace meets the requirements. Smelting of steel in an electric arc furnace using metalized pellets differs significantly from scrap smelting, first of all, by the melting period. When smelting metalized pellets there is a real danger of destruction of furnace slopes by aggressive waste rock slag. To create a flux from acid waste rock it is necessary to introduce lime, which leads to an increase in energy consumption for slag melting. Processes of additional reduction of iron oxides by excess carbon, occurring during the melting of metallized pellets, are associated with the release of carbon monoxide and lead to the boiling of slag, there is a possibility of slag emissions. The content of pellets in the charge over 20...30 % complicates melting and significantly worsens the process performance. The mentioned peculiarities of metallized pellets smelting cause the search for ways to create a more economical than electric arc furnace unit for processing of metallized raw materials into steel, capable to work on the charge of 100% sponge iron (Bersenev et al., 2021).

One of the tempting directions in the search for the technology of 100% conversion of metallized raw materials is the application of electroslag process for smelting. Works on electroslag smelting of sponge iron are being carried out on a wide front. It should be immediately stipulated that none of the works today has not passed the stage of pilot testing, and many of them are at the stage of laboratory studies.

The main working medium for melting metalized pellets is the slag bath. It is a generator of heat, thanks to which the melting of raw materials takes place. Pellets are fed into the slag bath at a temperature higher than their melting point. And despite the fact that the density of slag, as a rule, is somewhat lower or close to the density of metalized pellets, the latter, falling into the slag, do not sink and melt in the layer of slag (the density of real liquid slag at 1673 K is within 2.5 ... 3.15 t/m3). This circumstance, typical for classical electroslag remelting and quite unusual for steelmaking process, is of great importance: in the slag bath there is melting of charge, waste rock is separated from pellets, iron oxides pass into slag; practically all metallurgical reactions take place in it. Metal droplets falling into the metal bath already have the final chemical composition. Thus, the use of metallized pellets is very relevant for the production of consumable electrodes for electroslag remelting.

Research Results

The method of obtaining consumable electrodes for electroslag remelting, which consists in feeding metalized pellets into a mold and filling the mold with molten metal, was used for manufacturing electrodes. As a mold used a liner, in which installed in the center of the polystyrene rod with a diameter equal to 1/3 of the diameter of the liner, poured pre-dried at a temperature of 2000C for 4 hours. Then the molten metal was fed into the liner by siphon pouring from below in the volume of 1:3 vol.% to the volume of pellets, after the end of the crystallization process, the finished electrode is extracted.

The use of a polystyrene rod in the center of the liner allowed the pellets to be initially restrained from collapsing as the metal was poured in, and also ensured that the metalized pellets were densely impregnated as the liner was filled due to polystyrene combustion and filling of the liner with liquid metal.

The use of metallized pellets as a solid metallic phase makes it possible to obtain an electrode having a dense core evenly surrounded by pellets, which are joined to the core by impregnation of the latter with the poured metal. The material obtained as a result of further electroslag remelting has a low content of harmful gases, impurities of non-ferrous metals, which are not removed in the course of electroslag remelting.

Samples were cut out of the obtained ingots and examined on the electron microscope JEM 2100. On the basis of the obtained phase chemical composition we can conclude that the pellet is slightly melted, as evidenced by the increase in the carbon content in the boundary zone, relative to its content in the ligature. In turn, the pellet melting provides a strong bond with the ligature, and thus the required mechanical strength of the combined electrode for its further electroslag remelting.

The experiments were carried out at different temperature regimes of pellets heating, in the range from 200° C to 800 °C. For the experiments of pouring the pellet with the volume of ligature we used metallized pellets produced by OAO "Oskol Electrometallurgical Plant", the degree of metallization of which reaches 96.1 %, and as a ligature - soft iron.

Conclusions

When the pellets were preheated to temperatures of 600 and 800 °C, the ingots showed cavities around the pellet, which were formed due to CO release when the pellet was in contact with the liquid melt. Also, significant secondary oxidation prevented the alloying of the ligature and the metal component of the pellet, which contributed to its pitting when preparing the sample for microscopic analysis. When pellets were preheated to temperatures of 200 and 400 °C, as well as without preheating, no violations of ingot macrostructure were detected. The experiments have shown that the mechanical strength of the electrode, due to the fusion of the metal component with the ligature, is ensured by preheating the pellets to temperatures of 200 - 400 °C.

Acknowledgement

This work was supported by the Ministry of Science and Higher Education of the Russian Federation (grant FENU-2023-0013).

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