ISSN 0967-0912, Steel in Translation, 2019, Vol. 49, No. 7, pp. 478–480. © Allerton Press, Inc., 2019.
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Electrosmelting of Rail Steel from Directly Reduced Iron

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Received March 26, 2019

Abstract—According to research in the electrosmelting shop at AO EVRAZ ZSMK, the partial (up to 55%) replacement of chunk iron by hot-briquetted iron in rail-steel production is feasible and economically efficient. The phosphorus content in the steel is decreased by 0.003%, with constant content of nonferrous impurities. The use of hot-briquetted iron does not affect the productivity of the arc furnace. The consumption of power, natural gas, and coke increases when hot-briquetted iron is introduced in the metal batch. However, that may be compensated by the price difference between chunk iron and hot-briquetted iron.

Keywords: directly reduced iron (DRI), rail steel, arc furnaces, furnace performance

DOI: 10.3103/S0967091219070131

In the electrosmelting of steel, the shortage of metal scrap is a serious problem. With the conversion of steel plants to continuous casting and the subsequent closure of the cogging shops, the quantity of freshly produced scrap has declined considerably (Fig. 1). It has been replaced by recycled scrap—that is, worn-out parts, machines, and mechanisms, which are highly contaminated with nonferrous metals (Cu, Ni, Cr). That impairs the properties of the steel produced: in particular, its impact strength, crack resistance, thermal stability, and high-temperature strength. Researchers do not agree on the permissible content of such impurities. Considerable embrittlement occurs when the concentrations of the impurities in the steel are as follows, according to [1]: more than 0.16% copper; and a total content of the other nonferrous impurities higher than 0.02%. Surface cracks appear when the copper concentrate exceeds 0.15–0.34% (depending on the deformation temperature), according to [2]. In smelting and ladle treatment, those impurities—in particular, copper—are hardly removed from the steel; [3, 4]. The only effective method of decreasing the impurity content in the final steel is to replace some of the scrap with hot metal [5, 6].

In the case of rail steel, where low concentrations of nonferrous metals are required, electrosmelting by means of hot metal (and, later, cast-iron chunks) has been introduced at AO EVRAZ ZSMK [7–9]. According to State Standards GOST R 51685–2000/2013, the permissible impurity concentrations in ladle tests of rail steel are as follows: 0.20/0.15% Ni, 0.20/0.20% Cu, 0.20/0.20% Cr, –/0.010% Ti, –/0.27% Ni + Cu; and 0.50/0.40% Ni + Cu + Cr + Ti.

If more than 20% hot metal is used in the metal component of the charge, the concentration of nonferrous impurities in rail steel will be far below the upper limits. However, the ratio of the hot metal and scrap has a complex influence on the economics of rail-steel production, as shown, in particular, in [10]. With increase in the content of hot metal or iron chunks, the power consumption in the electrofurnace linearly decreases, while the oxygen consumption increases parabolically. The manganese content in the steel discharged from the surface decreases with increase in the liquid or solid iron consumption [10]. In the dependence of the smelting time on the iron content, there is a minimum at 35–40% for hot metal and 30–35% for cast iron [10].

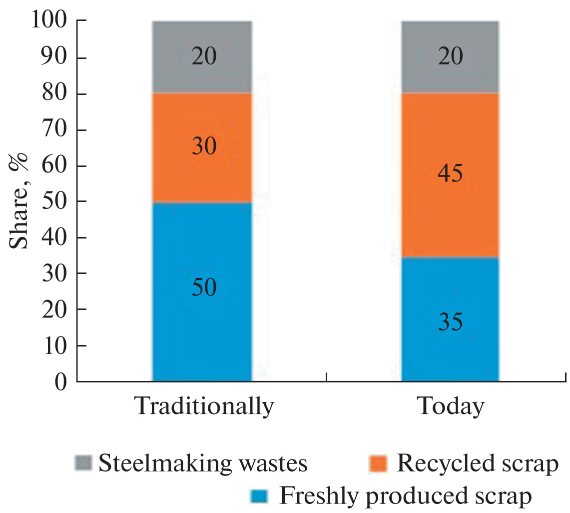

Fig. 1. Changes in the availability of freshly produced scrap, recycled scrap, and steelmaking wastes.

In addition, the production costs of rail steel depend on the relative prices of iron and scrap. Despite seasonal variations in scrap prices and occasional price spikes on account of scarcity, iron generally costs 10% more than scrap.

Increasing the proportion of iron in the metal component of the charge increases the phosphorus and sulfur concentration in the steel, on account of their high content in the iron. In particular, with increase in iron content in the metal component from 22 to 50%, the sulfur content in the steel discharged from the arc furnace increases, according to the data in [10]. Although existing methods of steel production considerably decrease the phosphorus and sulfur concentration, further decrease in their content calls for greater expenditures, with corresponding increase in cost of the steel.

Thus, we need to find alternatives to metal scrap in the electrosmelting of rail steel. In the present work, we analyze E76KhF rail steel produced in the electrosmelting shop at AO EVRAZ ZSMK by means of hot-briquetted iron, which is a form of directly reduced iron (DRI). In hot-briquetted iron, the iron content exceeds 90%, while the content of nonferrous metals (Cu, Ni, Cr, Mo) and also N, S, and P is low. That makes hot-briquetted iron a promising replacement for steel scrap in electrosmelting. When hot-briquetted iron is used, the phosphorus content in the steel is halved, with decrease in the sulfur content by a factor of 1.5, according to the data in [11]. Benefits of hot-briquetted iron as an alternative to scrap in electrosmelting include its high packing density (2.0–2.5 t/m^3) and its suitability for smelting without any preliminary treatment.

In Russia today, the only producer of hot-briquetted iron is Lebedinsk enrichment facility (a subsidiary of Metalloinvest). Since 2001, Lebedinsk enrichment facility has been producing hot-briquetted iron at a rate of 2.4 million t/yr. In industrial trials at the electrosmelting shop of AO EVRAZ ZSMK, hot-briquetted iron with the following characteristics is introduced in the batch: 90.87% FeO_{tot}; 4.23% SiO_2; 0.013% S; 0.008% P; 85.41% FeO_{met}; 1.27% C; 93.99% reduction; density 5 g/cm^3; and content of the <4-mm fraction 2.7%.

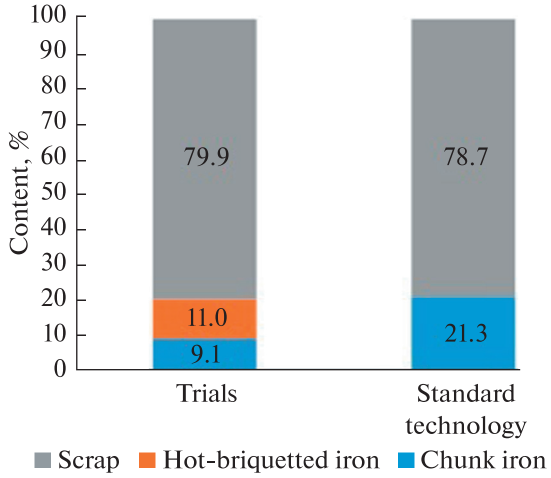

Fig. 2. Composition of metal batch in the electrosmelting of rail steel.

The mean consumption of hot-briquetted iron in each experimental melt is 13.68 t (corresponding to the range 13.6–13.8 t). In analyzing the influence of hot-briquetted iron on the smelting characteristics, the basis of comparison is electrosteel production at AO EVRAZ ZSMK in November 2018. In Fig. 2, we show the composition of the metal batch in the experimental trials in comparison with the standard batch for E76KhF rail steel.

Analysis of the data for the trials indicates the following consequences of using hot-briquetted iron in the batch (Table 1).

Table 1. Effect of using hot-briquetted iron in the electrosmelting of rail steel

Characteristic	Smelting		Deviation, %	
	with hot-briquetted iron	standard technology	absolute	relative, %
Smelting time (disregarding downtime), min	55	55	0	0
Consumption:				
oxygen, m^3/t	39.2	38.7	0.5	1.3
power, kW h/t	421.3	405.2	16.1	4.0
lime, kg/t	39.0	40.8	–1.8	–4.4
coke, kg/t	19.8	14.2	5.6	39.4
natural gas, m^3/t	4.9	4.7	0.2	4.3
Content at furnace discharge, %:				
C	0.064	0.139	–0.075	—
P	0.003	0.006	–0.003	—
Ni	0.081	0.080	0.001	—
Cu	0.115	0.115	0	—

(1) Decrease in the steel's phosphorus content (at the furnace exit) by 0.003%, on average. That is associated with decrease in lime consumption in dephosphorization by 1.8 kg/t (4.4%).

(2) Practically no change in residual Cu and Ni content in the steel.

(3) Decrease in carbon content of the steel by 0.075%. That is associated with increase in coke consumption by 5.6 kg/t (39.4%).

(4) Practically no change in smelting time.

(5) Increase in power consumption by 16.2 kW h/t (4%) and in natural-gas consumption by 0.2 m^3/t (4.3%).

Thus, partial replacement of hot metal (or cast iron) by hot-briquetted iron decreases the phosphorus content in the steel. The content of nonferrous impurities remains constant. The consumption of power, natural gas, and coke increases when hot-briquetted iron is introduced in the metal batch. However, that may be compensated by the price difference between chunk iron and hot-briquetted iron .Accordingly, noting also that the use of hot-briquetted iron has no influence on the furnace productivity, we may regard the use of hot-briquetted iron in the electrosmelting of rail steel as fully justified.

CONCLUSIONS

According to research in the electrosmelting shop at AO EVRAZ ZSMK, the partial (up to 55%) replacement of chunk iron by hot-briquetted iron in rail-steel production is feasible and economically efficient. This is important in view of the scarcity of high-quality scrap.

In the industrial trials, the phosphorus content in the steel is decreased by 0.003%, with constant content of nonferrous impurities.

The use of hot-briquetted iron does not affect the productivity of the arc furnace. The consumption of power, natural gas, and coke increases when hot-briquetted iron is introduced in the metal batch. However, that may be compensated by the price difference between chunk iron and hot-briquetted iron.

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Translated by Bernard Gilbert

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