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A study on the influence of the ratio of pig iron and metal scrap in the of electric melting charge on the technical and economic performances of the rail steel production

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Abstract. The article contains the results of the statistical study on the influence of the ratio of pig iron and metal scrap in the charge for the production of rail steel on the main technical and economic performances of the electric furnace shop. The regression curves obtained and substantiated from a technological point of view indicate a linear decrease in the specific consumption of electricity and an increase in the specific consumption of oxygen according to the parabolic law with an increase in the proportion of both hot and cold iron in the metal scrap. Also, a linear reduction in the manganese content at the tapping was observed with an increase in the proportion of pig iron in the metal charge. The dependence of the duration of melting on the ratio of the charge components in the metal scrap has a pronounced nonlinear character and indicates the presence of a pronounced minimum. The statistical model constructed on the basis of the dependencies obtained is an effective tool for optimizing the share of pig iron in the metal charge in the production of rail steel for a specific period of time, taking into account the level of prices for materials and energy carriers.

1. Introduction

At present, in the world of metallurgy, the bulk of the steel of rail grades is smelted in oxygen converters. In the domestic metallurgy the production of rail steel in the arc steelmaking furnaces is carried out only at “EVRAZ ZSMK” JSC.

The main reason for the rarity of rails production from electric steel is the problem for ensuring a low and stable level of impurities of residual elements (chromium, nickel, copper) in the steel, which can not be solved without significant additional costs or a sharp limitation of the raw material base.

Nevertheless, the production of rails from electric steel seems promising for a number of reasons [1, 2]:

- the electric arc furnace is a universal unit that allows a wide range of technological operations to be carried out with high efficiency, and it is well combined with out-of-furnace processing units and continuous casting plants.
- the broader technological capabilities of electric arc furnaces allow the production of improved metallurgical rails to be organized, including those intended for operation in particularly rough conditions.

In fact, the electric arc furnace is a more flexible unit than the oxygen converter in the following parameters [3-5]:

- maintenance of the given rate of melting, heating, decarburization, homogenization in temperature and chemical composition;
- the possibility of alloying (including direct alloying of steel) of a metallic melt;

- provision of a predetermined melting rate for slag-forming constituents, formation of homogeneous slag with a high refining capacity for carrying out dephosphorization in the furnace, and with the release of a slag melt from the furnace and desulphurization, which facilitates the removal of non-metallic inclusions and the degassing of the steel.

At “NKMK” (which is currently a part of “EVRAZ ZSMK” JSC), the technology of melting rail steel in 100-tonne arc electric furnaces with the use of hot iron was developed and has been implemented since 2000 [6-8]. Beginning in 2010, due to the closure of its own blast furnace production, cold (pig iron) iron is used in the metal charge.

It should be noted that the replacement of part of the scrap with cast iron is dictated, first of all, by the need to meet the requirements for the concentration of impurities of non-ferrous metals. At the same time, the technical and economic effectiveness of such a replacement is not always obvious.

In particular, the technology of using cast iron in electric melting has such technological and economic disadvantages as:

- increase in the slag number due to the high content of silicon in the cast iron, which in turn causes an increase in the cost of slag utilization, increase in ferro-alloys loss;
- increase in the lime consumption to obtain the required basicity of the slag, as well as an increase in heat losses with slag;
- increase in the consumption of manganese-containing ferroalloys due to a lower manganese content in cast iron than scrap metal;
- increase in the costs for metal charge due to higher cost of pig iron as compared to scrap metal;
- increase in the consumption of oxidants due to the need to remove carbon introduced by pig iron from the melt.

Although, at the same time replacing part of the scrap with cast iron in the metal charge makes it possible to achieve a number of significant advantages:

- reduce the fuel consumption (natural gas);
- reduce the consumption of carburizing agents (coke);
- reduce costs for the preparation of scrap metal for smelting;
- reduce the concentration of nitrogen in the steel, due to the intensification of the oxidation period and the overall decrease in the duration of melting;
- reduce the consumption of refractory products due to the decrease in temperature differences and the absence of mechanical destruction of the lining when heavy metal charge is loaded;
- reduce the contamination of steel by exogenous non-metallic inclusions.

In general, the assessment of the technical and economic efficiency of the use of cast iron in the metal scrap of electric arc furnaces and the choice of the optimal consumption of cast iron should be carried out for the conditions of the specific unit and taking into account the current level of prices for materials and energy carriers. Thus, to obtain quantitative dependencies that adequately reflect the real situation, a necessary condition is statistical processing of the data array for a specific aggregate over a period of time with stable production technology.

2. Methods of research

The effect of the composition of the metal charge on the technical and economic performance of the electric furnace shop at “EVRAZ ZSMK” JSC was studied by regression analysis. As a basis for the analysis, an array of 1000 batches of rail steel E76F (2007) and E76HF (2016) was used. The choice of these brands is due to their largest share in the assortment of the shop in question.

Indicators of production of rail steel were analyzed in periods characterized by the following production scheme [9, 10]:

- smelting in the arc steel smelting furnace using 30-60% of hot iron with subsequent out-of-furnace processing of steel in the unit “ladle-furnace” and casting on the continuous casting machine into billets with a cross section of 300×330 mm (2007);

- smelting in the arc steel smelting furnace using 20-50% cold (pig iron) iron, successive out-of-furnace processing on two ladle-furnace units and a vacuum furnace and casting on the reconstructed continuous casting machine into 300x360 mm billets(2016).

The influence of the metal scrap composition on the following performances indicators of electric furnaces during the smelting of rail steel was studied: the specific consumption of electricity, oxygen, lime, manganese and silicon content on the tapping (characterizes the consumption of ferroalloys), irrecoverable metal losses, duration of melting.

3. Results and discussion

As a result of the analysis, a significant influence of the metal charge composition on the following parameters was established: the specific consumption of electricity and oxygen, the manganese content at the tapping, and the duration of melting.

According to the data obtained, with an increase in the share of both hot and cold iron in the metal scrap, the specific energy consumption decreases linearly (figure 1).

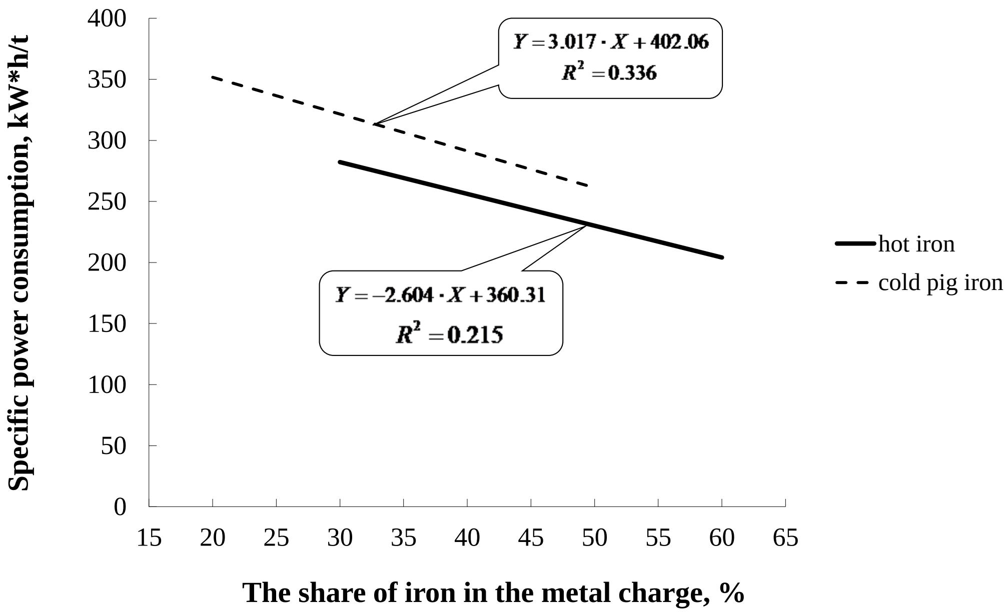

Figure 1. Dependence of the specific consumption of electricity on the share of cast iron in the metal scrap.

At the same time, the change in the consumption of hot iron slightly more significantly affects the power consumption compared to cold iron. This difference is due to the increased heat content of molten iron, which causes a reduction in the melting period. The lower melting point of cold iron as compared to the metal scrap also results in the decrease of melting time, which, however, is not as significant as in the case of hot iron.

The specific consumption of oxygen with an increase in the share of pig iron in the scrap metal increases according to the parabolic law (figure 2), regardless of the aggregate state of the cast iron used. The increased oxygen consumption is due to the need for oxidation of additional carbon added by the cast iron, and the parabolic nature of the obtained dependence indicates the increase in the intensity of oxygen blowing to reduce the duration of the oxidation period and the melting as a whole.

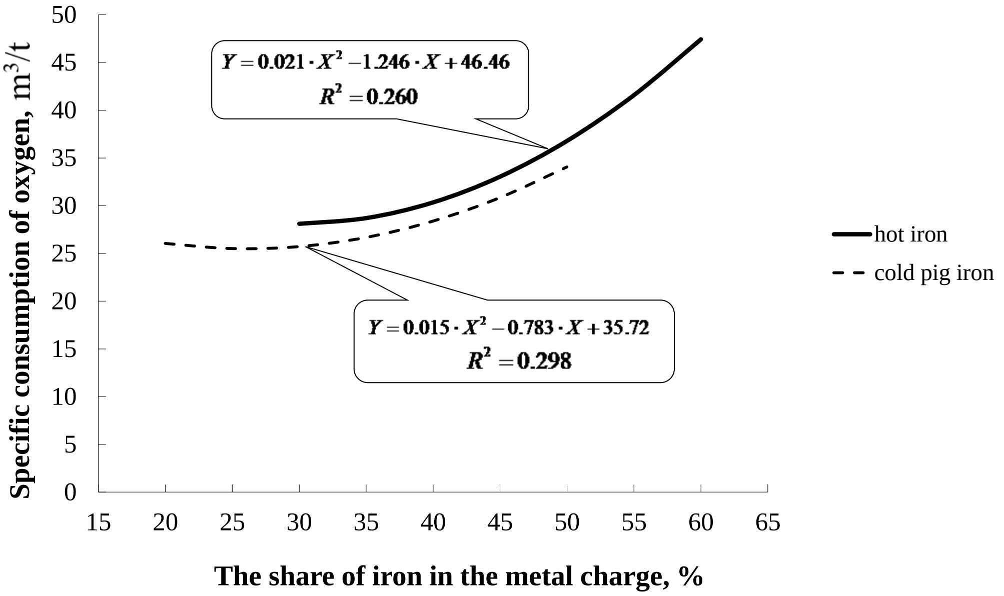

Figure 2. Dependence of the specific consumption of oxygen on the share of cast iron in the metal scrap.

The obtained results indicate a decrease in the manganese content at the tapping with the increase in the flow rate of cast iron to smelting (figure 3), which is explained by the reduced manganese content in pig iron relative to the scrap and increased manganese oxidation due to the increase in the duration and intensity of oxygen blowing.

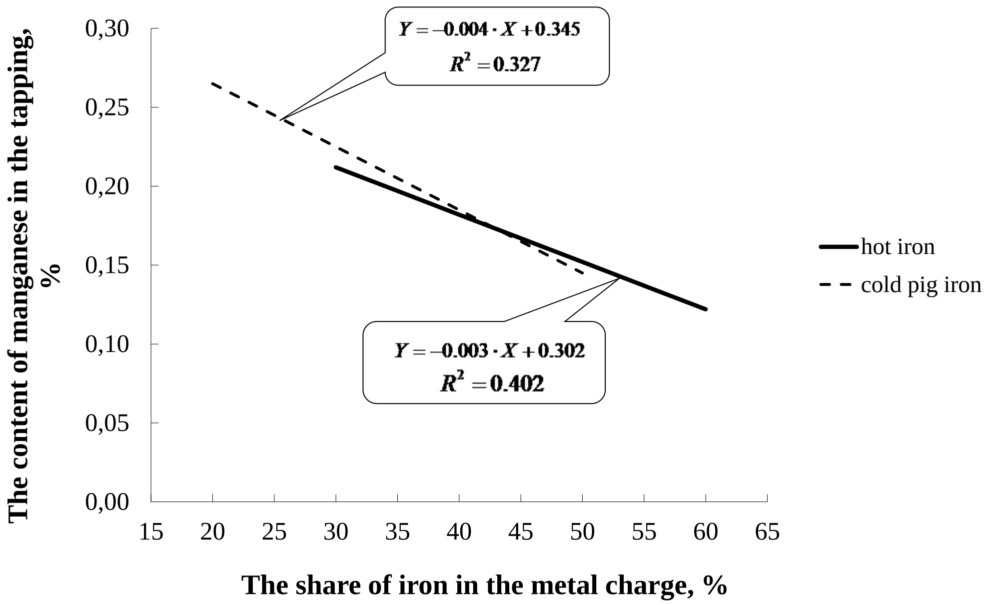

Figure 3. Dependence of manganese content at the tapping from the share of cast iron in the metal scrap.

The dependence of the smelting duration on the ratio of the charge components in the metal scrap shows that there is a pronounced minimum on the considered interval of variation in the consumption of cast iron (figure 4).

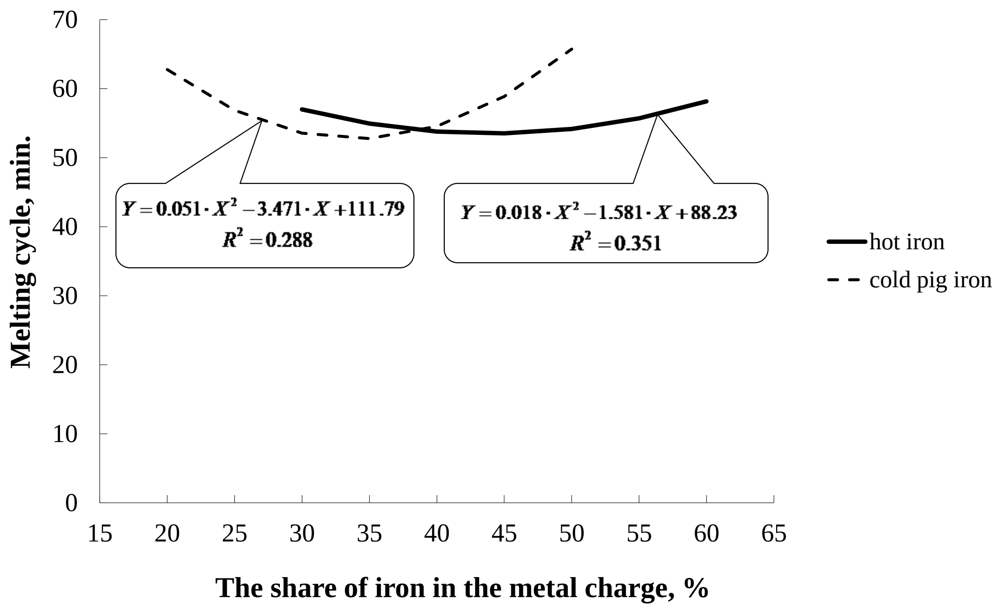

Figure 4. Dependence of the duration of electric melting on the share of cast iron in the metal scrap.

At the same time, when using hot iron this minimum is in the range of 35-40%, and when using cold iron it is 30-35%. This dependence is evidently due to the multidirectional influence of the increase in the consumption of pig iron on the duration of the melting periods (melting period, oxidation period, amount of additional charge of scrap) and nonlinear change in the duration of the periods themselves.

Thus, with the increase in the consumption of cast iron, the duration of the melting period decreases, while the duration of the oxidation period increases. In this case, as shown above, the increase in the consumption of hot iron has a stronger effect on the acceleration of melting of the charge compared to cold iron. Also, an increase in the consumption of cast iron leads to a reduction or total failure of scrap metal scrap, which naturally reduces the duration of melting.

Based on the obtained dependencies, a statistical model is constructed for the effect of the composition of the metal charge on the technical and economic performance of MSP during the smelting of rail steel. The following parameters we choose as optimization ones: total costs for cost items, which depend on the composition of the metal charge and the capacity of the shop in terms of proper continuous cast billets.

As forming costs the total costs for the components depending on the composition of the metal charge were: the cost for charge materials (pig iron and scrap), the cost for electricity, oxygen, ferroalloys:

The forming costs for the components, which depend on the composition of the metal charge, were as forming costs: the cost of the charge materials (pig iron and scrap), the cost of electricity, oxygen, ferroalloys:

$$C_{TOTAL} = (C_{P.IRON} \cdot P_{P.IRON} + C_{SCRAP} \cdot P_{SCRAP} + C_{EL.} \cdot P_{EL.} C_{OX.} \cdot P_{OX.} + C_{FER.} \cdot P_{FER.}), \qquad (1)$$

where C_{IRON}, C_{SCRAP}, $C_{EL.}$, $C_{OX.}$, $C_{FER.}$ – specific costs of pig iron, scrap, electricity, oxygen and ferroalloys, respectively; $P_{P.IRON}$, P_{SCRAP}, $P_{EL.}$, $P_{OX.}$, $P_{FER.}$ – the price of pig iron, scrap, electricity, oxygen and ferroalloys, respectively.

The consumption of manganese-containing ferroalloys is inversely proportional to the content of manganese in the tapping. Taking into account the manganese content in the ferroalloy and its loss, the specific consumption of ferroalloys will be determined by the following formula:

$$SC_{FER.} = \frac{10 \cdot (C_{FIN} - C_{TAPPING})}{C_{FER.} \cdot (100 - L)}, \text{ t/t} \tag{2}$$

where C_{FIN} – content of manganese in the finished steel, %;
$C_{TAPPING}$ – manganese content in the tapping, %;
C_{FER} – manganese content in the ferroalloy, %;
L – manganese loss, %.
The productivity of the shop was determined by the formula:

$$P = \frac{1440 \cdot M}{100 \cdot T} \cdot Y \cdot F, \tag{3}$$

where M – is the mass of the metal scrap, t;
Y – metal yield,%;
F – worktime fund of the shop, day/year.
T – melting cycle, min.
The model is implemented in the spreadsheet program “Excel” and works as follows. As changing input data, the following are used: prices for pig iron, metal scrap, electricity, oxygen and manganese-containing ferroalloys, as well as parameters such as the average weight of the metal scrap, the yield, the actual operating time of the shop, the average manganese content in ferroalloys, manganese loss during deoxidation and alloying.

After entering the initial data, the program calculates the forecast values of electricity, oxygen, manganese content in the tapping, and the duration of melting using the regression equations shown in figures 1-4. Then, the forecasted value of total costs is calculated by the line items, depending on the ratio of pig iron and scrap in the metal charge and the predicted productivity of the workshop. The received data are displayed on the screen in the form of graphs.

The use of the developed model allows sound recommendations on the optimal share of pig iron in the metal scrap to be developed for the current price level for materials used for electric smelting and energy carriers and also taking into account the change in the shop productivity.

4. Conclusion
The statistical studies carried out for the conditions of the electric steelmaking shop of “EVRAZ ZSMK” JSC established qualitative and quantitative dependences of the technical and economic indicators of the production of rail steel on the ratio of pig iron and scrap in the metal charge. The resulting regression relations formed the basis of the model, the use of which makes it possible to develop sound recommendations on the optimal proportion of pig iron in the metal charge for a particular period, taking into account the current level of prices for materials and energy carriers, and also taking into account the change in the productivity of the shop.

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