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Research the impact of steel scrap participation in the metallic charge for the yield of liquid steel casted in BOF process

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ABSTRACT

Purpose: The basic purpose of this publication is to demonstrate the influence of variations in composition of the metallic charge in the Basic Oxygen Steelmaking process on the converter performance. One of the methods considered is in increase of the content of steel scrap. The preliminary results of the researches carried out demonstrate such a possibility and improvement of the liquid steel per melt ratio.

Design/methodology/approach: The used research methodology consists in analytical simulation of variations in mass of liquid steel obtained from melts differing in steel scrap content in the metallic charge and statistical analyses of industrial results acquired from the corresponding process documentation (so called melt cards).

Findings: Basing on the analytical and statistical analyses carried out we have determine resulting variations in the liquid steel per melt ratios depending on the content of steel scrap in the metallic charge.

Research limitations/implications: The research results obtained can be utilized in each steelmaking facility, which employs the Basic Oxygen Steelmaking process, in order to “design” the metallic charge compositions, having in view the quality and economic aspects.

Practical implications: The research results presented in the paper can be used for steel production of high purity steels.

Originality/value: The results presented in this paper are directed to the steelmakers employing the Basic Oxygen Steelmaking process and constitute the authors’ original study.

Keywords: Metallurgy; Ferrous scrap; Oxygen converter; Liquid steel

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MATERIALS MANUFACTURING AND PROCESSING

1. Introduction

Steel scrap belongs to the most essential components of metallic charge in the Basic Oxygen Steelmaking (BOS) process. The standard scrap content in mass of the metallic charge ranges from 20 to 25%. From the process point of view the steel scrap performs a role of an adjustment factor in the heat balance of each steel melt [1-11]. In industrial conditions, depending on the current market situation and supply of pig iron, the content of steel scrap in the oxygen furnace charge varies both in the direction of decreasing and increasing as well. These variations, independently of the steel scrap quality by no means influence the run of steelmaking process, as well as its technical and economical characteristics, determining the converter performance. Taking into account variations in the metallic charge component proportions used in the industrial practice, it will be useful to carry out the analysis of the influence of such variations, as well as the steel scrap quality on the converter performance measured by means of the liquid steel per melt ratio.

2. Steel scrap characteristics

Steel scrap quality is closely connected with its source of origin. In consideration of the source of origin the steel scrap is divided, according to PN-85/H-15000 standard, into following three categories [12]:

- the circulating scrap generated in different phases of steel making and steel product manufacturing. The $Z_{ob}^{(n)}$ quantity of the circulating scrap generated in year n can be determined with the formula:

$$Z_{ob}^{(n)} = P_S^{(n)} \cdot k_{ob} \text{, Mg/year} \tag{1}$$

where: k_{ob} - circulating scrap return coefficient,

- the post-fabrication scrap, which comprises wastes generated in the manufacturing processes connected with processing steel products. The $Z_{pp}^{(n)}$ quantity of such scrap generated in year n within the area of a territorial entity can be expressed by means of the dependence:

$$Z_{pp}^{(n)} = P_{WS}^{(n)} \cdot k_{pp} \text{, Mg/year} \tag{2}$$

where:
k_{pp} - post-fabrication scrap acquisition coefficient, which depends not only on the amount $P_{WS}^{(n)}$ of steel product output within area of the entity under consideration, but also on foreign trade operations concerning the steel products,

- the post-demolition scrap comprising the worn out and/or damaged steel goods (equipment, structures, transportation means etc.), which have lose their original useful properties (including morally obsolete goods). The $Z_{pa}^{(n)}$ amount of post-demolition scrap acquired is in close dependence with the amounts of steel products manufactured in the previous years and the speed at which they wear out:

$$Z_{pa}^{(n)} = P_{WS}^{(n-t)} \cdot \frac{n}{100} \text{, Mg/year} \tag{3}$$

where:
$P_{WS}^{(n-t)}$ - steel consumption in form of steel products per year, Mg/year,
t - the time, after which the piece of goods becomes worn out (it is usually assumed to be 15-20 years),
n - coefficient of steel reuse in form of post-demolition steel scrap, which fluctuates in the range from 30 to 70%.

The circulating scrap, due to its place of origin, can be characterized as having high density and "metallurgical" purity. Also its chemical composition is well known. The post-demolition scrap (also called commercial steel scrap by the steel makers) is considered to be the scrap of lower quality in comparison with the circulating scrap. It can be characterised with high level of differences in chemical composition observed in a specific volume unit, lower density and some pollutants in form of non-ferrous metals and non-metallic materials. Changes in steel scrap markets (resulting from decrease in the circulating scrap supply) together with modern and effective processing methods implemented at the same time into the industrial practice, such as the steel scrap pre-processing (e.g. shredding) have caused that now the demolition scrap has become the predominant metallic component of the converter charges in the BOS steelmaking processes

3. Determination of the liquid steel per melt ratio in the BOS process

The metallic charge in the BOS process is composed of liquid pig iron and steel scrap mixed according to precisely defined proportions. The obligatory operation in the final phase of steel making in the oxygen converter is the preliminary steel deoxidation, most often performed during tapping with use of well fitted **ferrous alloys**. The iron derived from the deoxidizing process will increase the mass of liquid steel in each melt. This is why the ferrous alloys used should be also included in the metallic charge, and the "ferrous" part of the alloy mass should be taken into account when determining the liquid steel per melt ratio. Based on the assumptions made the liquid steel per melt ratio can be expressed with the formula [10,13,14]:

$$W_U = \frac{M_{CS}}{M_S + M_Z + \frac{1}{3} M_{FS}} \cdot 100\ \% \tag{4}$$

where:
M_{CS} - the mass of liquid steel obtained in the melt, Mg
M_S - the mass of liquid pig iron used in the melt, Mg
M_Z - the mass of steel scrap used in the melt, Mg
M_{FS} - the mass of ferroalloys, Mg

4. Simulation of the influence of steel scrap on the steel per melt ratio

Three variants of the steel scrap content in converter metallic charge have been assumed in the research of simulation of steel scrap influence on the steel per melt ratio in 330 Mg BOS converter:

- variant 1 → $U_Z = 10\%$; $U_S = 90\%$
- variant 2 → $U_Z = 20\%$; $U_S = 80\%$
- variant 3 → $U_Z = 30\%$; $U_S = 70\%$

5 Mg of ferroalloys (FeMn and FeSi) have been used in each variant for the purpose of steel deoxidation, one third part of what, i.e. 1.666 Mg, has become part of the molten metal, increasing the mass of liquid steel in the melt. Table 1, raws no. 1 and 2, present the chemical composition, assumed for calculations, of metallic charge materials, i.e. the liquid pig iron and steel scrap. In the result of oxidising reactions of chemical elements contained in the metallic charge (carbon, manganese, phosphorus and iron), as well as desulphurization reactions the amount of molten metallic charge decreases and its chemical composition changes. The final chemical composition of molten metallic charge prior to tapping has been assumed identical for each melt variant - Table 1, no. 3. The mass values for elements removed from the metallic charge due to the oxidizing reactions are presented in Table 2.

Table 1.
Chemical composition of pig iron, ferrous scrap and metal bath before tapping, %

No.	Charge component	C	Mn	Si	P	S
1	Pig iron	4.50	0.40	0.50	0.10	0.05
2	Steel scrap	0.30	0.50	0.30	0.04	0.04
3	Molten metal prior to tapping	0.04	0.10	-	0.04	0.04

Table 2.
Decrement of elements in metal bath, Mg in simulated variants of melts

Chemical element	Variant 1	Variant 2	Variant 3
Δ m_C, Mg	13.332	11.946	10.560
Δ m_{Mn}	1.023	1.056	1.089
Δ m_{Si}	1.584	1.518	1.452
Δ m_P	0.178	0.158	0.138
Δ m_S	0.029	0.026	0.023
Δ m_{Fe}	4.020	4.620	4.620
Equal	20.766	19.324	17.882

The Δ m_{Fe} iron loss from the metal charge in 4.620 Mg quantity in each melt variant corresponds to 18 percent content of FeO in the slag. During deoxidation of the liquid metal charge with the M_{FS} mass of deoxidizers (ferroalloys) the M_{CS} mass of liquid steel will increase by one-third of M_{FS}. Using the formula (1) we can determine the Wu liquid steel per melt ratio for each simulated variant of steelmaking in the BOS converter (Table 3).

Table 3.
Rate of obtaining liquid steel from the melt,%. Rate of obtaining liquid steel from the melt,%

Variant no.	Simulation parameters	
	M_{CS}, Mg	W_U, %
Variant 1	310.899	94.21
Variant 2	312.341	94.65
Variant 3	313.783	95.09

Graphical illustration of the carried out simulations of the influence of steel scrap content in the metallic charge on the liquid steel per melt ratios is presented in Fig. 1. Taking into account the iron loss in form of sludge contained in the converter gas in 2.498 Mg quantity (for variant 2, assuming 10 kg of dust - sludge per Mg, containing 70 % of FeO), the liquid steel per melt ratio will decrease to the value Wu=93.87%, i.e. by 0.76 %.

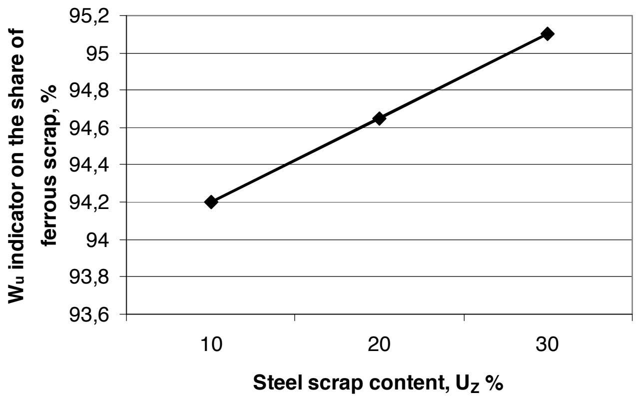

Fig. 1. Dependence of Wu indicator on the share of ferrous scrap in metallic charge

5. Results of statistical analysis

The research has been carried out on population of 10000 steel melts made in the BOS converter of 330 Mg volume. In the analysis of the influence on the Wu liquid steel per melt ratio, we have included such parameters as: U_z total scrap content, U_{zo} circulating scrap content, U_{zpa} demolition scrap content, U_{FS} ferroalloy content. The linear regression method has been utilized in the analysis. Results of the analysis carried out are presented in graphical form in Figs. 2-5. We should state, when assessing the results of statistical analyses of the influence of use of steel scrap in the metallic charge in the BOS process, and in the researched process conditions, that the steel scrap used (circulating scrap and post-demolition one) does not essentially influence the BOS process performance measured with the liquid steel per melt ratio. In other words the steel scrap used is of high quality, what attests to its good preparation to the steelmaking process. We should explicitly state, when generalizing the results of research carried out (simulation research and statistical analyses), that the use of steel scrap as the component of BOS process metallic charge does not cause decrease in the liquid steel per melt ratio.

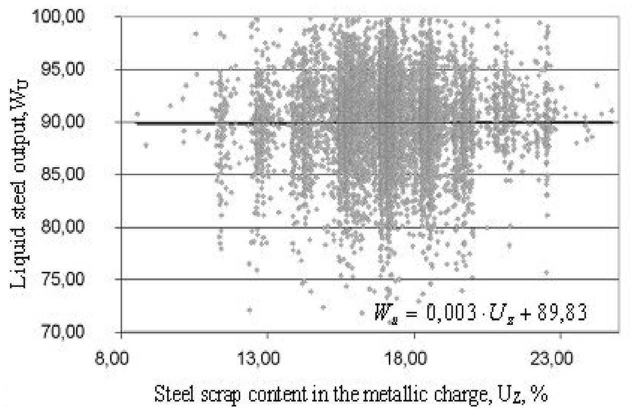

Fig. 2. Dependence of liquid steel output from the melt on the share of scrap in metallic charge

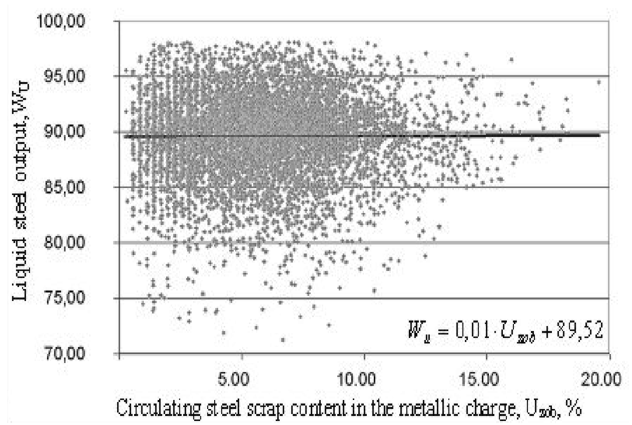

Fig. 3. Dependence of liquid steel output from the melt on the share of process scrap in metallic charge

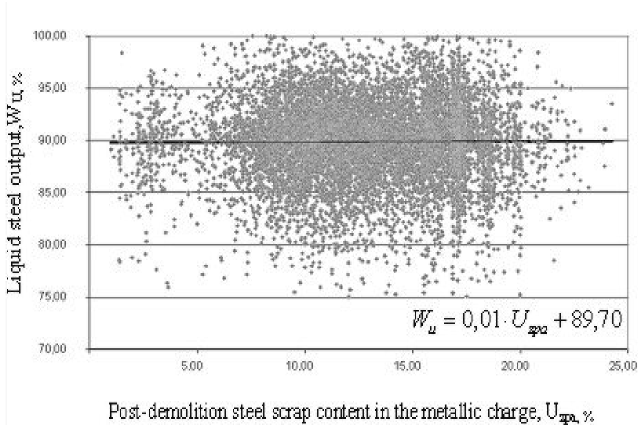

Fig. 4. Dependence of liquid steel output from the melt on the share of post-absorbtion scrap in metallic charge

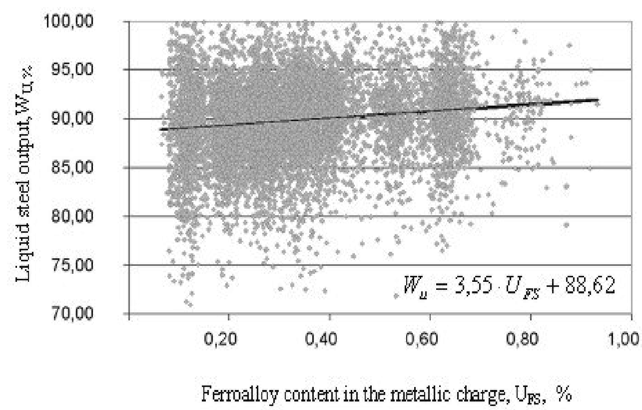

Fig. 5. Dependence of liquid steel output from the melt on the share of ferroalloys – deoxidizers

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