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Abstract

The Steel Scrap Purity Analysis in the Context of the Quality of Steel Produced at AMW †

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1. Introduction

The basic input material for steel production in an arc furnace is steel scrap, which is the main material contributing iron to the melting process [1]. The criteria for classifying steel scrap and the description of its quality are the subjects of many national standards regulating trade rules. Standards usually divide steel scrap by type, classes, categories, groups and degree of corrosion. The standards usually also include preparation requirements for batch and non-batch scrap. Preparation of batch scrap, both unalloyed and alloyed, includes sorting, cutting and pressing. Sorting pieces of input scrap according to dimensions and weight is intended to assign their size and type to specific classes. The standards also include the division of scrap according to its chemical composition. Alloy scrap and unalloyed scrap with limited content of certain elements should be sorted into categories and groups depending on their chemical composition. The presence of alloyed scrap, alloyed cast iron, non-ferrous metals and their alloys is unacceptable in unalloyed scrap.

General standards rarely describe the chemical composition of scrap in detail, but this composition is very important for the steelmaking process. It determines technological activities, and it is a key element, especially in the process of melting steel in an electric arc furnace [1]. The content of oxidizable elements can be removed from the metal bath, but the products of these reactions are oxides that pass into the slag, affecting its properties and the technological process. However, non-oxidizable elements pass completely into the metal bath and remain in the chemical composition of the produced steel. This applies in particular to the content of elements in scrap that occur in small amounts but significantly affect the properties of steel, such as copper, tin, and antimony.

The research results contained in the article were implemented within the framework of a project executed by ArcelorMittal Warsaw in the sectoral program “INNOSTAL”, financed by Measure 1.2 “Sectoral R&D programs” and the priority axis “Support for business R&D” of the Smart Growth Operational Program, 2014–2020; agreement no. POIR.01.02.00-00-0161/16. The aim of the implemented project was to develop and implement innovative technologies for the production of super-clean steels for the automotive industry in the context of improving the quality of rolled products intended for automotive vehicle components. The project’s assumptions focused on significantly improving the metallurgical purity of products by reducing the number and size of non-metallic inclusions revealed in microscopic and ultrasonic tests and reducing the total oxygen content. One of the tasks was to analyse the purity of steel scrap used for the steelmaking process in terms of the content of undesirable elements in the conditions of ArcelorMittal Warsaw.

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2. Analysis of the Content of Undesirable Elements in Scrap

In order to identify the undesirable elements in AMW production conditions, an analysis was carried out on the content of these elements in the produced steel, originating from the charge and which cannot be removed in the steelmaking process. The results of the analysis were presented graphically in the form of charts as a function of the so-called scrapping procedures. In AMW production conditions, the batch composition, i.e., the selection of the amount, form and content of basic elements in the scrap used for individual loading baskets, is carried out in accordance with scrap procedures described as "procedure" A, B, C, D or E. Each of these procedures has defined the scrap selection criteria. The average values of the content of copper, arsenic, tin, antimony and lead are presented in Table 1, calculated separately for melts made according to individual procedures. Figure 1a–e graphically presents the average content of subsequent elements for individual scrap selection criteria.

Table 1. Average values of concentrations of selected elements in steel (melting analysis).

Scrap Selection Criteria	Cu, %	As, %	Sn, %	Sb, %	Pb, %
A	0.2325	0.0067	0.0153	0.00249	0.00029
B	0.1917	0.0061	0.0118	0.00220	0.00030
C	0.1509	0.0049	0.0096	0.00217	0.00029
D	0.1240	0.0046	0.0086	0.00200	0.00038
E	0.0571	0.0020	0.0030	0.00129	0.00031

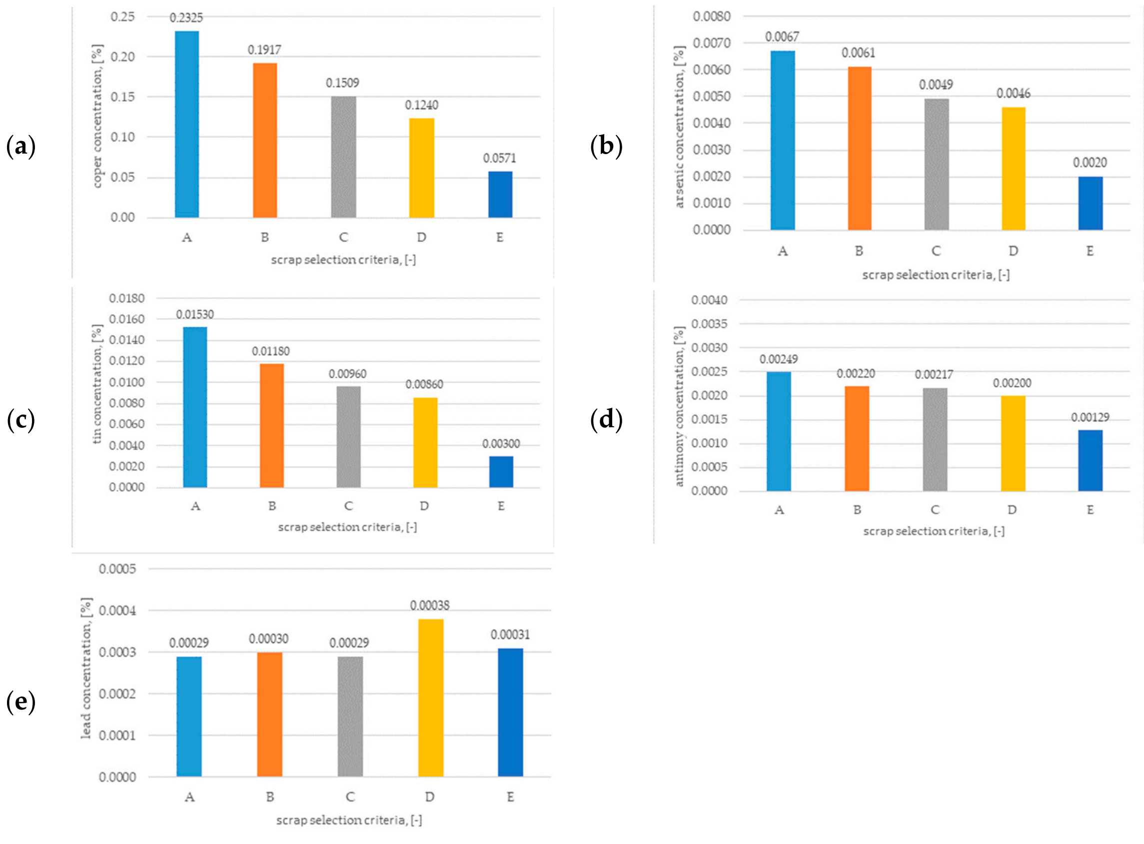

Figure 1. Average: (**a**) coper, (**b**) arsenic, (**c**) tin, (**d**) antimony, (**e**) lead concentrations in steel depending on the scrap selection criteria used to compile the charge.

Copper, having limited solubility in iron, precipitates at grain boundaries at hot plastic processing temperatures, causing grain melting and cracking of the steel. With a copper content above 0.08% in the temperature range of 850–1100 °C, the steel is prone to cracking during plastic forming. Even low copper contents clearly worsen the susceptibility of steel to plastic deformation, especially during cold extrusion [2].

Due to its limited solubility in solid iron, tin has a high tendency to segregate during solidification. This weakens the cohesion of the steel grain boundaries and deteriorates the plastic properties (impact strength and fatigue strength). Sn content above 0.05% in steel significantly reduces plastic deformability, especially during cold extrusion. During hot forming (850–1100 °C), tin causes steel to crack. The unfavorable effect of tin on the properties of steel increases in the presence of copper. Arsenic and antimony cause hot embrittlement, especially of harder steels, both carbon and alloy [2].

Lead reduces the cohesion of steel grain boundaries and impairs plastic properties. Additionally, lead, due to its high density and low melting point, if it is present in scrap in larger quantities during its rapid melting in an arc furnace, segregates and penetrates into cracks in the lining of the refractory hearth, which increases the rate of its destruction [2].

The average copper (Figure 1a) concentration in steel depends significantly on the procedure used. The highest concentrations are obtained for procedure A, while the lowest for procedure E. It follows from the above that for steel grades with a higher copper content, scrap procedure A can be used, while for steel grades with a narrower Cu limit, procedure B, C or D must be used accordingly, but for grades with a low copper content, procedure E must be used.

The average concentration of arsenic (Figure 1b) in steel, similarly to copper, depends significantly on the procedure used. The highest concentrations are obtained for procedure A, and the lowest for procedure E. It follows from the above that for steel grades in which a higher arsenic content is allowed, scrap procedure A can be used, while for steel grades with a narrower As limit, the appropriate procedure B, C, D. For species with a low permissible arsenic content, procedure E must be used.

The average concentration of tin (Figure 1c) in steel also depends significantly on the procedure used. The highest concentrations are obtained for procedure A, and the lowest for procedure E. It follows from the above that for steel grades in which a higher tin content is allowed, scrap procedure A can be used, while for steel grades with a narrowed Sn limit, it must be used according to procedure B, C or D, but for species with a low permissible tin content, procedure E must be used.

The average concentration of antimony (Figure 1d) in steel also depends significantly on the procedure used. The highest concentrations are obtained for procedure A, and the lowest for procedure E. It follows from the above that for steel grades in which a higher antimony content is allowed, scrap procedure A can be used, while for steel grades with a narrowed Sb limit, procedure B, C or D must be used accordingly, but for species with a low permissible antimony content, procedure E must be used.

The average concentration of lead (Figure 1e) in steel slightly depends on the procedure used. For procedures A, B, C and E, very similar concentrations are obtained, only for procedure D a significantly higher concentration was obtained. It follows from the above that from the point of view of the lead content in steel, the procedure used is of little importance, any procedure can be used. Only for steel grades in which a higher lead content is allowed, scrap procedure D can be used.

3. Guidelines for the New Technology for the Production of Super-Clean Steels at the ArcelorMittal Warsaw Steel Plant

For the purposes of guidelines for the development of updates to steel production technology, a detailed statistical analysis of process data was performed. The most important process parameters were analysed in the following technological stages: smelting in an arc furnace, refining in a ladle furnace, refining in a vacuum and continuous steel casting, separately for each group of steel grades.

The subject of analysis in the context of steel purity was also the obtained K3O and K4O steel purity indexes according to DIN 50602. The work also analysed the total oxygen content. Due to the small number of results for individual species groups, these results were not presented in the charts. It should be noted that the steels currently produced at ArcelorMittal Warszawa were characterised by high metallurgical purity. The average value of the K4O index was 0.9 and the K3O index was 2.3. The average total oxygen content was 10 ppm. Nevertheless, there are cases where the above-mentioned values are significantly exceeded—e.g., the value of the K3/K4 ratio for one of the melts was over 20, and the maximum total oxygen content reached 19 ppm. Statistical analyses indicate that there is still a significant risk of not meeting the requirements set as the goal to be achieved in the project. The basis for the development of these guidelines was the results of industrial research, including analyses of the chemical and phase composition of non-metallic inclusions, tests of slag characteristics and simulation tests using the developed model for the formation, flotation and removal of non-metallic inclusions from a metal bath. Additionally, the results presented in this work were considered. These include analyses of harmful elements in scrap, statistical evaluations of steel production parameters according to existing technology, cause-and-effect relationships between smelting parameters and quality indicators, and the results of analyses of the chemical composition of internal defects detected in ultrasonic tests. The above research was the basis for developing guidelines for a new steelmaking process technology in the production of steel for the automotive industry.

One of the conditions for a significant improvement in the quality of rolled products intended for motor vehicle components is the appropriate cleanliness of the scrap in terms of the content of undesirable elements. In the production conditions of AMW, the composition of the input, i.e., the selection of the amount, form and content of basic elements in the scrap used, is carried out in accordance with scraping procedures. Each of these procedures has defined scrap selection criteria. The analysis of the content of copper, arsenic, tin, antimony and lead showed that in all cases the levels of the analysed elements are consistent with current technological instructions. It is suggested not to make any changes to the procedures used.

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