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OPTIMIZATION RECYCLING IN IRON AND STEEL METALLURGY: UTILIZATION OF BY-PRODUCTS FOR EFFICIENCY AND SUSTAINABILITY

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ABSTRACT – This research focuses on the systematic examination of by-product reuse, with a particular emphasis on the recovery of valuable metals from slag—a critical by-product of the metallurgical process. The recovered metals are carefully classified into three categories: A-Scrap, B-Scrap, and C-Scrap. Each category is assigned specific applications: A-Scrap is utilized in steel production, B-Scrap serves in blast furnace operations, and C-Scrap finds its use in sintering processes. The study delves into the economic advantages, enhanced resource utilization, and ecological benefits stemming from these recycling practices. By reducing dependency on primary raw materials, such practices not only cut costs but also conserve finite natural resources and mitigate the environmental impact of industrial activities. In this context, the research aims to advance the use of secondary raw materials, contributing to a steel manufacturing process that is both more efficient and environmentally responsible. By integrating innovative recycling methods, this study aspires to support the transition towards a greener and more sustainable metallurgical sector, aligning with global efforts to reduce industrial emissions and promote eco-friendly practices.

Keywords: Recycling, Metallurgy, Agglomeration, Blast Furnace, Steel Plant.

INTRODUCTION

Steel production is one of the key industrial processes that enables the development of modern technologies and infrastructure. Today, the majority of global steel production is achieved through the Basic Oxygen Furnace (BOF) process, which efficiently converts raw iron into high-quality steel.

Starting from the sinter plant, where in the ore mixture for the purposes of sinter production, secondary materials such as mill scale, blast furnace and steel sludge, blast furnace dust together with screening from ore, pellets, sinter and other materials used by the blast furnace plant are very often used [1].

A notable example of metallurgical recycling is the reintegration of return and discarded materials generated across the production facilities, optimizing the reuse of metallic waste and using it in steel plant [2]. Since these materials are already in a reduced metallic state, their use minimizes the demand for additional reducing agents and significantly lowers the emission of harmful gases into the environment [2].

This paper focuses on the recycling of by-products generated in the steel production

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process, with a particular emphasis on slag utilization. The slag produced during the converter process can be further processed and used in multiple ways. A portion of the slag is returned to the process as a secondary raw material for smelting, reducing the need for primary raw materials and increasing production efficiency. Additionally, a significant portion of the slag is processed and used in the construction industry, primarily as a raw material for cement and concrete production. This practice not only contributes to the economic viability of steel production but also reduces the industry's environmental footprint, enabling sustainable industrial waste management.

MATERIALS AND METODS

One of the key materials suitable for recycling in the iron and steel industry is the metal fraction recoverable from slag after the slag separation process, prior to its transfer into the converter at the steel plant. The processing of steel plant slag (converter and mixer slag) for HBIS Serbia in Smederevo is carried out by the partner company HARSCO Metals, which is located within the factory. The slag, transported in ladles from the Steel Plant to HARSCO, is poured into designated cooling fields. After cooling, it is crushed using a ROXON MR PLANT crusher with magnetic separators, where the slag is separated based on granulometric composition and iron content. The processing results in the following products: A Scrap (170-250mm), B Scrap (10-170mm), and C Scrap (-10mm), as well as waste material (10-50mm).

This process yields three distinct scrap categories—A-Scrap, B-Scrap, and C-Scrap—which are utilized as metallic additives in the steelmaking process, blast furnace operations, and sintering plant, respectively.

Beyond other recyclable materials, the steel plant can incorporate A-Scrap as a metallic additive, enhancing the overall recycling rate while mitigating industrial pollution. B-Scrap, characterized by a finer granulation than A-Scrap, is well-suited for blast furnace operations, where it can be introduced into the burden structure as a metallic supplement. C-Scrap, which has the finest granulation among the three, is particularly effective in sintering applications, where it contributes to sinter production.

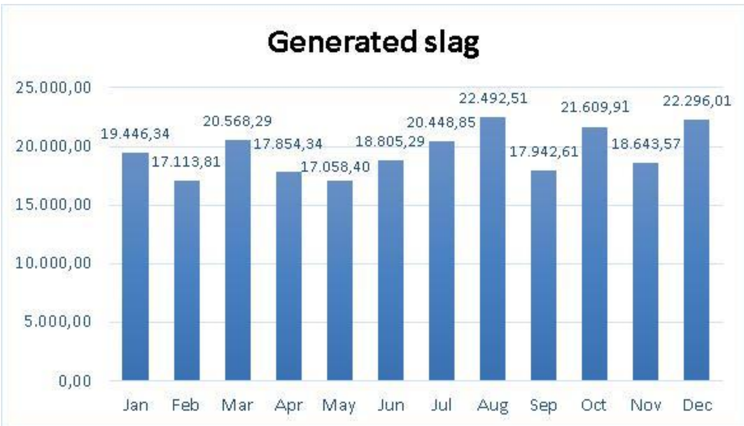

Figure 1 Generated slag at the Steel Plant by month in 2024

In 2024, a total of 234,279.93 tons of the slag generated from the Steel Plant was handed over to the processing operator. Of this, 8.97% was sold to cement plants, 47.89% was disposed of at the landfill, and 43.14% was returned to the production process as three raw materials for three production plants, what can be seen in Figures 1 and 2.

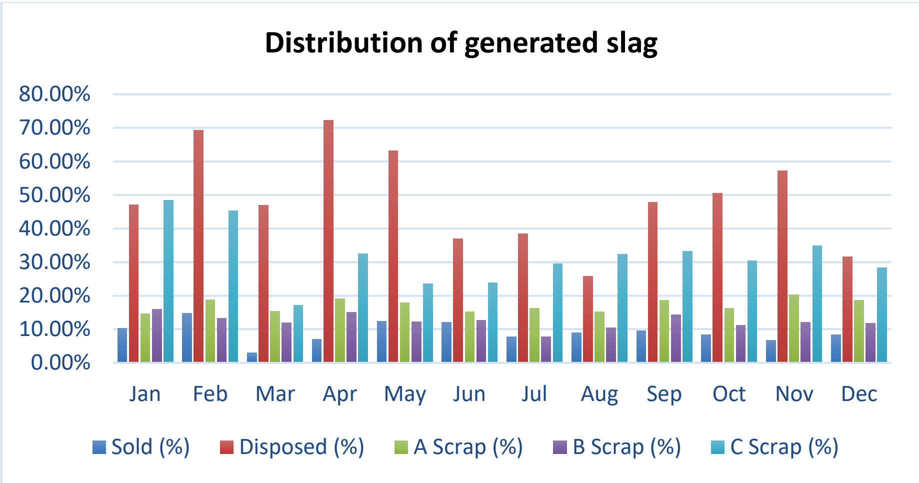

Figure 2 Distribution of generated slag by month in 2024.

RESULTS AND DISCUSSION

A-Scrap is a high-quality metallic by-product obtained from the processing of steelmaking slag, utilized in steel production due to its significant iron content. The replacement coefficient for A-Scrap in the steelmaking process indicates that 1 ton of A-Scrap can substitute up to 0.85-0.95 tons of iron in the raw material mix, thereby increasing metallic yield and reducing the demand for primary raw materials. Its utilization enhances energy efficiency, as it already contains metal in a form suitable for melting, leading to lower electricity consumption and reduced use of reductants. The implementation of A-Scrap in the raw material mix contributes to a decrease in specific energy consumption per ton of produced steel, while simultaneously reducing waste generation and improving material circularity within the production process.

By integrating A-Scrap into the steel scrap structure, with an average share of 12.35%, a cost reduction of $8.9 per ton of processed slab is achieved. The utilization of by-products from steelmaking not only provides economic benefits but also optimizes resource use, making the production process more sustainable. The consumption of A-Scrap and its impact on cost efficiency are illustrated in Figure 3. This model demonstrates potential for long-term application while maintaining the quality of the final product.

Materials used for iron production are sinter, pellets, lump ore and B-scrap. In the last year, the structure of the burden and chemistry of materials has not varied much, which allowed experimentation with the percentage of B-scrap used in the burden structure. The burden is consists of 60% sinter, 15% lump ore, 3-5% B-scrap and rest pellets. Fuels used in iron production include coke and PCI, with PCI serving as an auxiliary fuel with a replacement ratio of 0.85 units of coke consumption. The usual content of Fe in the B-scrap that has been used ranges from 65-70%.

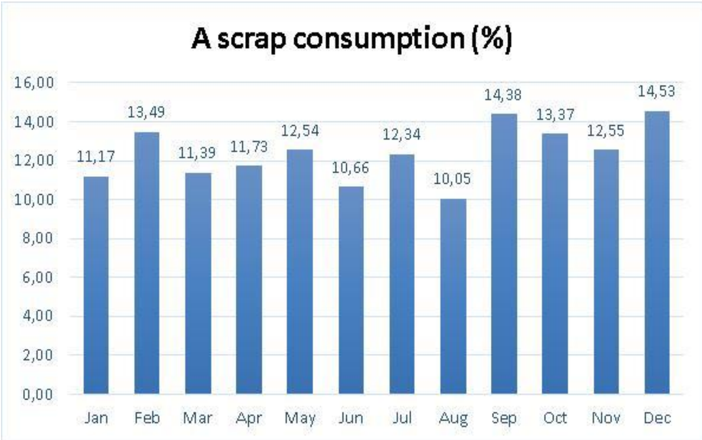

Figure 3 A Scrap consumption in 2024.

Three experimental phases were evaluated, each characterized by distinct B-scrap proportions of 0%, 3%, and 5%. The accompanying diagram elucidates the correlation between equivalent fuel consumption and the proportion of B-scrap within the burden.

B-scrap is a material that enhances the blast furnace burden by increasing the Fe content. However, it is also a significant source of phosphorus. Therefore, an increase in the percentage of B-scrap can lead to problems in hot metal quality in that regard. To better control the phosphorus levels in the iron and to monitor the impact of B-scrap on fuel consumption, the proportion of B-scrap in the burden was adjusted over the course of time. B-Scrap implementation in BF burden yields in average 20kg/thm lower total fuel consumption for 5% B-Scrap proportion, shown in figure 4. The financial aspect of utilizing B-scrap is reflected in the fact that, if the share of B-scrap increases to 2% at the expense of pellets, the price of iron decreases by $9.3 per ton of hot metal.

In a sinter production process, a certain amount of recycling materials is used in order to improve physical and chemical properties and to reduce the cost of sinter production. One of them is a C-Scrap.

Benefits of this material are numerous. Fe content is 40-42%. Coeffitient of substitution, compared to average iron ore used in our Sinter plant is 0.65. This means that we don't have to buy around 47,500 tons of iron ore on annual level.

Grain size is very favorable and it is similar to some of the best iron ores in the world. High percentage of 3.6-8.0mm grains provides increase of pelletization center for sinter mixture, thus creating good air permeability and increase productivity of Sinter line. C-Scrap is a material that already had heat treatment, so introducing it into the sinter mixture decreases the amount of fuel needed for sintering and that significantly reduces the cost of sinter.

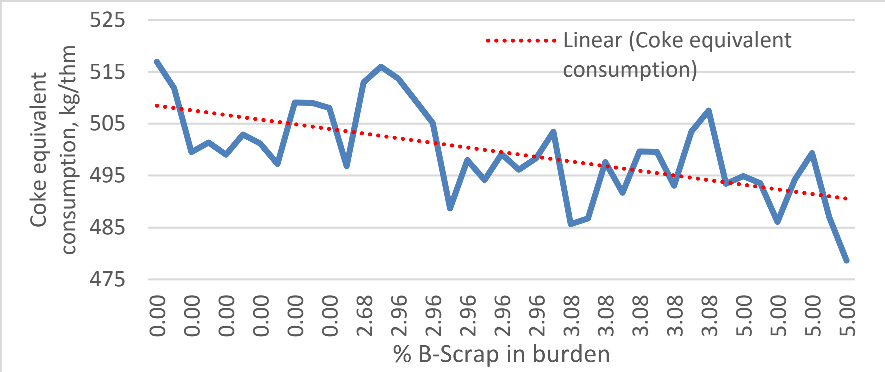

Figure 4 Coke equivalent consumption for different B-Scrap proportions

When we calculate amount of C-Scrap that we can use, main factors are phosphorus content in raw iron ores and percentage of sinter used in burden structure of the blast furnace. Our multidisciplinary teams worked on a calculations of a most favorable ore composites and burden structure in order to achieve the lowest possible cost of a casted slab and to remain competitive on a steel market. Currently we use 60% of a sinter in a BF structure. That provides us to use 10-12% of a C-Scrap in a sinter mixture, without jeopardizing the chemistry of a final product with a phosphorus. C-Scrap consumption is shown in figure 5.

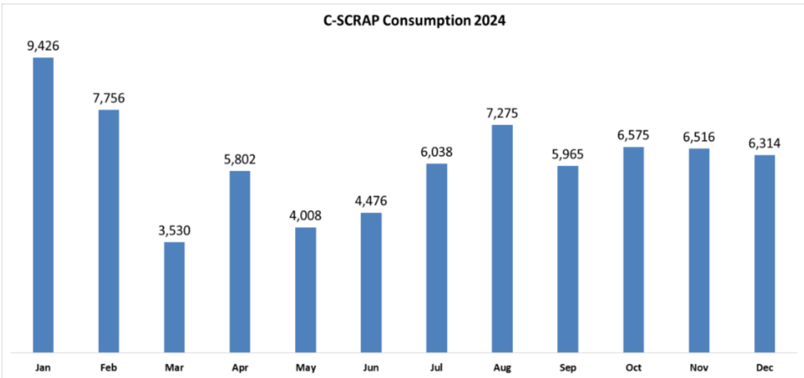

Figure 5 Consumption of C-Scrap on annual level

Speaking in numbers, Sinter plant of a HBIS Company currently uses cca 6,100t of C-Scrap per month, which is around 74,000 tons annually. Low cost of a processing and delivery of this material, compared to purchase of iron ore saves our Company around 4.7 million dollars per year. Use of a C-Scrap in a sintering process also contributes to the environmental protection, making it easier for us not to store so much waste material.

Considering trends and forecasts on a iron and steel market, C-Scrap is and shall remain one important strategic resource for providing competative price of our steel products.

CONCLUSION

The recycling and reutilization of waste materials in steel production, particularly the use of A, B, and C scrap types, are crucial steps toward improving efficiency, reducing costs, and minimizing environmental impact. The incorporation of A-Scrap into steel production has led to significant cost savings by reducing the need for primary raw materials and enhancing energy efficiency. Additionally, the use of B-Scrap in the blast furnace process and C-Scrap in sintering helps lower coke consumption, increases productivity, and reduces harmful gas emissions.

The use of these secondary raw materials not only provides economic benefits but also supports the sustainable development of the steel industry, enabling competitiveness in the market while minimizing environmental impact.

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