Processing of ferrous iron and steel waste in the context of the circular economy

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Abstract. The paper presents the possibilities of exploiting the small and powdered ferrous waste with the production of lighters that can be used as a raw material in the loading of the steel processing units. The capitalization of small ferrous and powdered iron and steel wastes is an important problem, because their transformation into by-products, so in economic goods can lead to a rational exploitation of the resources of raw materials and energy, thus ensuring both the needs of the human society and the protection of the environment surrounding.

1. Introduction
A sustainable circular economy is an economy in which each company is actively involved in the rational use of resources and waste recovery processes. Steel is considered a fundamental material in the circular economy. Steel products are vital to meet the needs of society, and steel production faces a wide range of challenges related to raw material resources, energy consumption, pollution reduction and recovery of waste from current production or storage flows [1].

The main solid by-products resulting from steelmaking are: steel slag, electro-filter dust and sludge. Figure 1 shows the fields of use of metallurgical slag worldwide, in 2016 [2].

Electric arc furnace slag from carbon steel production is a by-product of melting steel scrap in an electric arc furnace. Most frequently found mineral components for this slag is presented in Table 1 [3].

| Most frequently found mineral components       | Molecular formula                        |
|-----------------------------------------------|------------------------------------------|
| larnite, beta-dicalcium-silicate               | beta-Ca$_2$SiO$_4$                       |
| srebrodolskite, calcium-iron-oxide            | Ca$_2$FeO$_5$                            |
| brownmillerite, calcium-aluminium-iron-oxide  | Ca$_2$AlFeO$_5$                          |
| Spinel                                        | Me$^{2+}$Me$^{3+}$O$_4$                  |
| wuestite, solid solution of iron(II)-oxide with MgO and MnO | (Fe$_{1-x-y}$Mg$_x$Mn$_y$)O$_2$            |
| gehlenite, calcium-aluminium-silicate         | Ca$_3$Al$_2$SiO$_7$                      |
| bredigite, calcium-magnesium-silicate         | Ca$_{14}$Mg$_2$Si$_8$O$_{32}$            |
In the steel industry it is common to represent the composition of ferrous slags by ternary phase diagrams. Figure 2 present simplified diagram the components \([\text{CaO} + \text{MgO}], [\text{SiO}_2, + \text{Al}_2\text{O}_3]\) and \([\text{FeO} + \text{MnO}]\) were chosen as end points since these are the main components which form the most frequently found mineral phases listed in the Table 1 [4-8].

![Figure 1. Use of iron and steelmaking slags in Europe (41Mt in 2016)](image1.png)

![Figure 2. Ternary phase diagram - electric arc furnace slag from carbon steel production [3]](image2.png)

At present, special attention is paid to the processing technologies of recoverable waste, resulting from the current manufacturing flows of those stored. Waste management through recovery is an ecological and economic priority. The circular economy stimulates the increase of the economic value simultaneously with the decrease of the consumption of natural resources [4], [9-12]. The steel industry is an integral part of the circular global economy that promotes zero waste, reduces the amount of materials used and encourages the reuse and recycling of materials. The ecological concept applied to metallurgical engineering involves the development of those closed-loop production technological flows in which no resource is disposed of, all materials are continuously reused, no hazardous waste or other product is discharged into the environment [5], [13-21]. We are constantly...
trying to identify and implement the most efficient methods for retaining all possible sources of iron content within the production-use-recycling cycle in order to protect natural resources, reduce costs and impact of waste disposed of on the environment.

2. Experimental research in the laboratory phase

The steel slag currently resulting from the manufacturing flows during the manufacture of steel is stored in dumps. For laboratory experiments, slag samples were taken from the dump. The steel slag processing plant has a capacity of 500t/h. The slag with a grain size of less than 250 mm is introduced into a hopper from where it is taken over by a belt feeder provided at the end with a magnetic drum with a diameter of 1000 mm and an active length of 1200 mm. The slag barks with dimensions larger than 250 mm will remain on the grid of the installation and the result is the fraction over 250 mm that is directed for shipment to the steel plants. The fraction with granulation below 250 mm is separated magnetically and is classified resulting from processing 3 sorts: 0-10 mm ferrous material, 10-50 mm ferrous material, 50-250 mm ferrous material and deferred material. Figure 3 shows the SEM analysis of the steel slag (EAF) stored on the dump.

Figure 4 shows the slag processing plant and the aprons resulting from the processing. The non-ferrous fraction is also processed, sorted by sorts and used in other fields (construction, cement industry, agriculture, etc.).

For the research carried out in the laboratory, samples of ferrous material were taken from the three varieties (Figure 5): 0-10mm, 10-50mm and 50-250mm.

The paper presents the results obtained from tests and research on the recovery of ferrous material - steel slag - ferrous fraction with a grain size of less than 10 mm in the form of briquettes. The experiments focused on the use of ferrous material with a grain size of less than 10 mm because it is the least reused fraction. Due to the restructuring of the steel plant, its use in the agglomeration sector is not possible. To obtain the experimental briquettes, the ferrous material (granulation below 10 mm) was used, resulting from the processing of steel slag mixed with ferrous sludge resulting from the steel industry.

![Figure 3. SEM observation and EDS spectrum [3]](image-url)
The ferrous material taken from the dump was subjected to particle size separation in the laboratory using a vibrating screen. 1, 3, 5, 8, and 10 mm square meshes were used to classify the fraction below 10 mm. The particle size classes (0-3mm, 3-5mm, 5-8mm, 8-10mm) resulting from the classification are presented in Figure 6.

The chemical composition of ferrous waste used to obtain experimental lighters is shown in Figure 7.

Lighters were made according to 4 recipes. Composition of recipes: 30% ferrous fraction from steelmaking slag (R1 - 1mm granulation, R2 - 3mm granulation, R3 - 5mm granulation, R4 - 8mm granulation), 30% sludge mill scale, 30% ferrous sludge, 5% sintering sludge and 5% bentonite for binders. The technological flow of briquetting is shown in Figure 8. The average chemical composition of the tested lighters is shown in Figure 9. These aspects from the time of experiments (experimental briquettes) are shown in Figure 10.
Figure 7. Chemical composition of ferrous waste: a- ferrous fraction from steelmaking slag; b- sintering sludge; c- ferrous sludge; d- sludge mill scale
Experimental technology for briquetting processing:
- Preparation of ferrous waste (ferrous slags of steel slag with a grain size of less than 10 mm, sludge mill scale, ferrous sludge and sintering sludge) for raw batch formation
- Determination of chemical and particle size composition per batch subject to processing; - Dosing the materials according to the established recipe, for a weight of the briquetting batch of 2 kg;
- Homogenization of materials in the homogenization drum, the time for this operation is about 10 minutes;
- Briquetting of the material with the help of the hydraulic press;
- Hardening of lighters in the oven;
- Determination of the qualitative characteristics (chemical composition and compressive strength) for each batch of briquettes.

The lighters were hardened in the oven according to the diagram shown in Figure 11.

![Figure 8. The technologic flux of obtaining briquettes](image)

![Figure 9. Chemical composition of briquettes](image)
The briquetting process allows the processing of a wide range of waste with an iron content of 25-75% and from a particle size point of view, from microns to a maximum of 10mm. Experimental briquettes are capitalized by melting in steel aggregates. In order to determine the qualitative characteristics, the compressive strengths were determined, the results obtained confirming an appropriate resistance for the transport and handling of the resulting by-products.

3. Conclusions

Small and powdery waste from the steel industry, due to its high content of iron, manganese, carbon and various oxides (elements useful in the production process of cast iron or steel) are called by-products and are considered components of natural capital because they are used in the steel industry. The research was focused on the recovery of the following ferrous waste: the ferrous fraction from steelmaking slag, ferrous sludge, sludge mill scale and sintering sludge.

The qualitative characteristics regarding the strength and chemical composition of the briquettes obtained (48% Fe) are appropriate for their use as a metal assortment in the load of electric arc furnaces in the proportion of 5-10% (may be equivalent to ferrous bark).

The processing of small and powdery ferrous waste can be done by briquetting, the choice of waste from the recipes must be made by the processor, which must take into account the availability of waste, the demand for resulted products, economic and environmental aspects.

Figure 10. Experimental briquettes

Figure 11. Experimental briquettes
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