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RESEARCH REGARDING THE CAPITALIZATION OF THE WASTE RESULTED FROM THE STEEL INDUSTRY

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The circular economy applies to all areas of activity and is a concept of production and consumption that involves the reuse, repair, renovation and recycling of materials / products. Current legislation requires the finding of solutions for the transformation of waste stored or resulting from current manufacturing flows into by-products usable in industry. The paper presents the possibilities of capitalization of small and powdery ferrous waste resulting from the steel industry by transforming them into by-products in the form of agglomerate. The resulting by-products are used as raw material in the steel industry.

Keywords: Ferrous Pulverous Waste, Co-products, Valorification, Siderurgy

1. Introduction

The concept of circularity is correlated with the efficiency of the use of natural resources at system level, respectively throughout the entire life cycle of products, as well as with the transformation of waste into new resources for other industries [1]. The Waste Framework Directive 2008/98/EC [2] sets out the waste hierarchy and the criteria for defining by-products. Directive (EU) 2018/851 [3] on waste management places particular emphasis on prevention, including reuse, preparation for reuse and recycling in accordance with the waste hierarchy. The circular economy reflects the strategy of sustainable development, through which natural resources are used sustainably to protect the environment as the economy grows, in order to gradually achieve high efficiency, a low-cost economy in which pollutant emissions are reduced and the rate recycling is high. The circular economy is a means of economic development with high efficiency and low emissions. The present and the future belong to the circular economy, whose basic principle is the reintroduction into the production cycle of all waste resulting from production cycles [4, 5].

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In a well-structured circular economy, steel has significant advantages over other materials, namely: reduction, reuse, recovery and recycling [4]. Steel production results in the generation of co-products that can reduce CO_2 emissions by replacing resources in the steel industry and other industries.

The circular economy means a radical change in the way resources are used throughout the economy. An important goal is to identify sustainable solutions to optimize the consumption of resources for closing loops. The new recycling targets for each waste stream, the ban on storage in 2030, the need to implement prevention plans require a high degree of readiness for Romania [5-9].

The recovery and use of steel industry by-products has contributed to a material efficiency rate of 97.6% worldwide. Recovered by-products can be reused during the steelmaking process or sold for use by other industries [7, 10].

This prevents landfill waste, reduces CO_2 emissions and helps preserve natural resources. The sale of these by-products is also economically sustainable. It generates revenues for steel producers and forms the base of a lucrative worldwide industry [8, 11-13].

2. Experiments in the laboratory phase

The small ferrous and powdery wastes generated on the technological flow sectors of the steel industry are shown in Fig. 1.

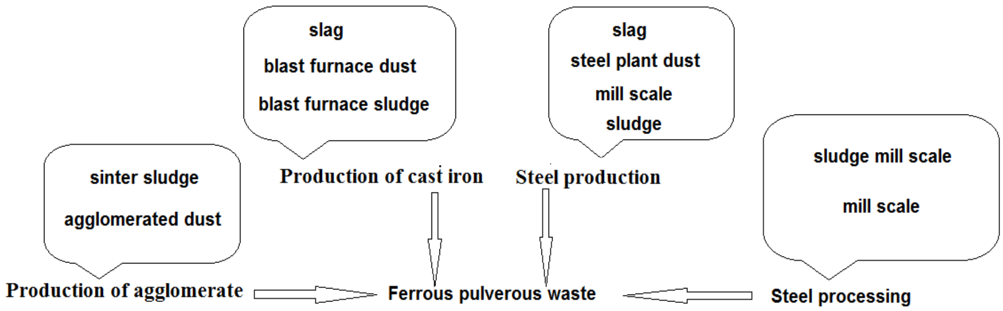


Fig.1. Ferrous pulverous waste

In integrated plants - blast furnace (BF) - basic oxygen ant (BOF) the rout accumulates approximately 400-450kg by-products/ton of crude steel [7, 14]: 275kg/t ironmaking slag (BF), 125kg/t steelmaking slag (BOF) and the rest of ironmaking dust and sludge (BF and BOF). In electric arc furnace (EAF) route accumulates approximately 190-200kg by-products/ton of crude steel [7]: 170kg/t steelmaking slag (EAF) and the rest of steelmaking dust and sludge (EAF).

In Hunedoara area, as a result of the restructuring of the Steel Plant, the primary flow was completely decommissioned: coking plant - agglomeration -

furnaces - Siemens-Martin-Blooming steelworks. Under these conditions, small and powdery ferrous waste, both those currently resulting from production flows and those deposited in landfills can no longer be recycled through the agglomeration process, as the primary flow no longer exists, they are stored.

For the capitalization and reintroduction of these wastes in the economic circuit, simple technologies are proposed that do not involve high costs for processing. The experimental technologies, in the laboratory phase, for establishing the material solutions, compatible with the recovery of ferrous, powdery and small waste, are: the production of pellets, briquettes or agglomerate (discontinuous agglomeration installations).

The paper presents the laboratory research carried out on the possibilities of recovery by agglomeration of powdery and small ferrous waste resulting from the steel industry, namely: tundra, tundra sludge, ferrous sludge, agglomeration sludge and steel slag 5 mm).

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. They were subjected to magnetic separation. For laboratory tests, steel slag was used - the ferrous fraction with a grain size of less than 8 mm. The chemical composition of small ferrous and powdery wastes used for laboratory testing is shown in Tables 1-5.

The powdered ferrous waste was subjected to granulometric analysis and their granulometric composition is shown in Figures 2-4. The SEM analysis of the slag, mill scale and ferrous sludge samples is presented in Fig.5

Table 1

Chemical composition of mill scale

Fe [%]	FeO [%]	Fe_2O_3 [%]	SiO_2 [%]	MnO [%]	Others [%]
66.42	7,40	86,66	0,50	0,86	4,58

Table 2

Chemical composition of ferrous fraction from steelmaking slag

Fe_2O_3 [%]	SiO_2 [%]	Al_2O_3 [%]	CaO [%]	MgO [%]	MnO [%]	P_2O_5 [%]	Cr_2O_3 [%]	Na_2O [%]	Altele [%]	Fe [%]
27.64	20.29	4.56	27.94	8.00	4.82	0.30	1.02	1.09	4.34	19.35

CaO/SiO_2=1.38

Table 3

Chemical composition of sintering sludge

Fe [%]	FeO [%]	Fe_2O_3 [%]	SiO_2 [%]	Al_2O_3 [%]	CaO [%]	MgO [%]	MnO [%]	S [%]	P [%]	C [%]	P.C. [%]
30.25	8.74	33.5	10.15	9.23	10.2	2.47	0.89	1.38	0.13	22.04	1.27

CaO/SiO_2=1.01

Table 4

Chemical composition of ferrous sludge

Fe [%]	Fe_2O_3 [%]	SiO_2 [%]	Al_2O_3 [%]	CaO [%]	MgO [%]	MnO [%]	Cr_2O_3 [%]	Na_2O [%]	P_2O_5 [%]	Other oxides [%]
66.54	95.06	0.91	0.23	0.30	0.71	0.27	0.05	0.77	0.01	1.69

CaO/SiO_2=0.33

Table 5

Chemical composition of sludge mill scale

Fe [%]	Fe_2O_3 [%]	SiO_2 [%]	Al_2O_3 [%]	CaO [%]	MgO [%]	MnO [%]	Cr_2O_3 [%]	Na_2O [%]	P_2O_5 [%]	Other oxides [%]
62.70	89.57	3.15	1.14	2.12	0.65	1.70	0.28	0.39	0.05	1.23

CaO/SiO_2=0.67

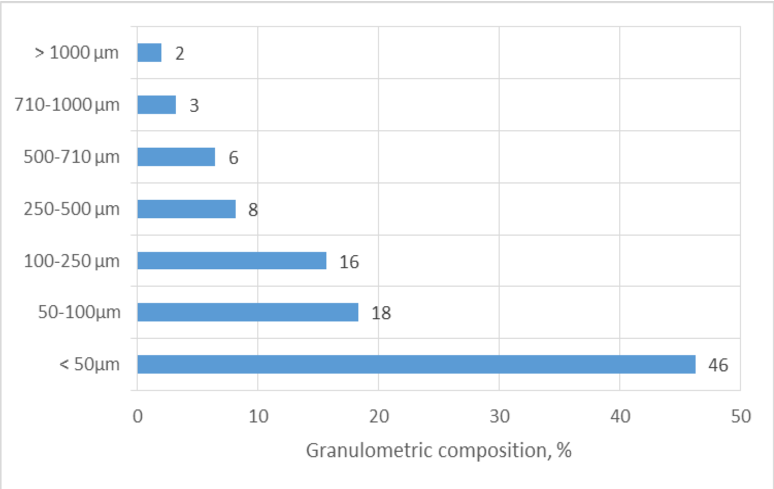


Fig.2. Sintering sludge granulometric classes

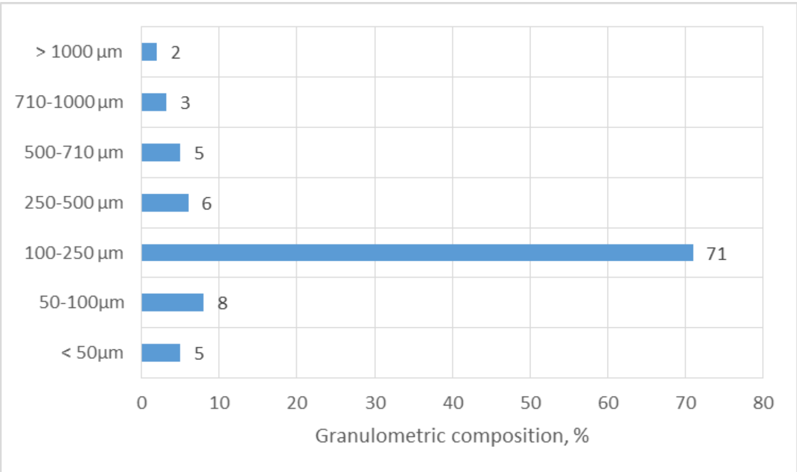


Fig.3. Ferrous sludge granulometric classes

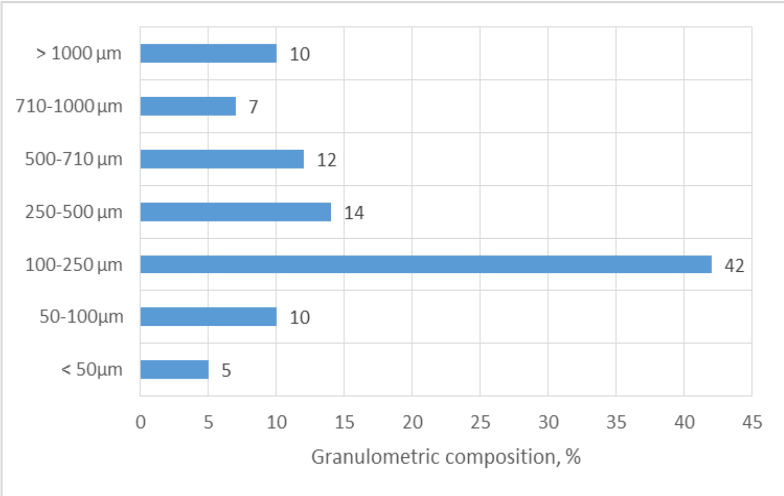
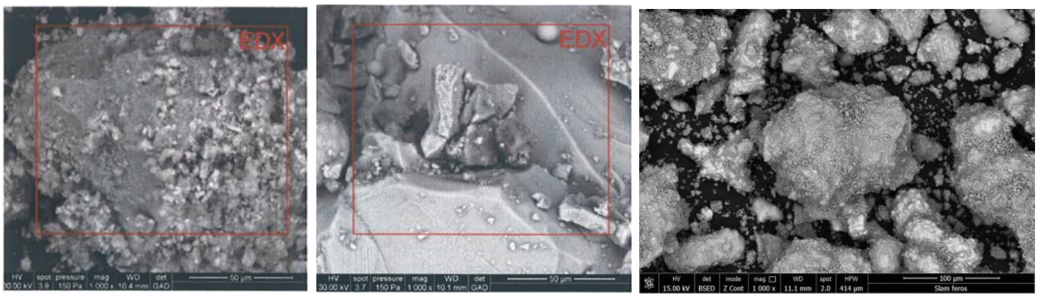


Fig.4. Sludge mill scale granulometric classes



Slag, 1000x Mill scale, 1000x Ferrous sludge, 1000x

Fig.5. SEM analysis

Analyzing the chemical and granulometric composition of the samples, the technology of their processing by agglomeration in the agglomeration box was established. Due to the granulation of the sludge samples, they were subjected to micropelletization with the help of the tray-type pelletizing plant. The sludge samples were subjected to the pelletizing operation and bentonite was used for binders, according to the technological flow shown in Fig. 6. The obtained micropellets were used to obtain the agglomerate. Two recipes were made, their composition being presented in table 6.

The mill scale was subjected to the grading operation, the fraction larger than 5 mm being reintroduced to the mill (in the Kollergan mill). The coke was ground to a granulation of max. 3mm. The quality of the agglomerate and the fuel consumption are directly influenced by the degree of grinding of the fuel. The optimal granulation of the fuel (0.5-2 mm) at agglomeration, leads to minimum consumption and its good quality [10]. Coke fractions larger than 2 mm and especially those of 3 mm develop large amounts of heat by combustion, and lead to an overheating of the agglomerated mixture, and the fine fraction below 0.5 mm is easily reactive and the resulting heat is not used efficiently. The fuel must be as homogeneous as possible mixed with the materials subjected to agglomeration, so that in the sintering process too high local temperatures are avoided [10].

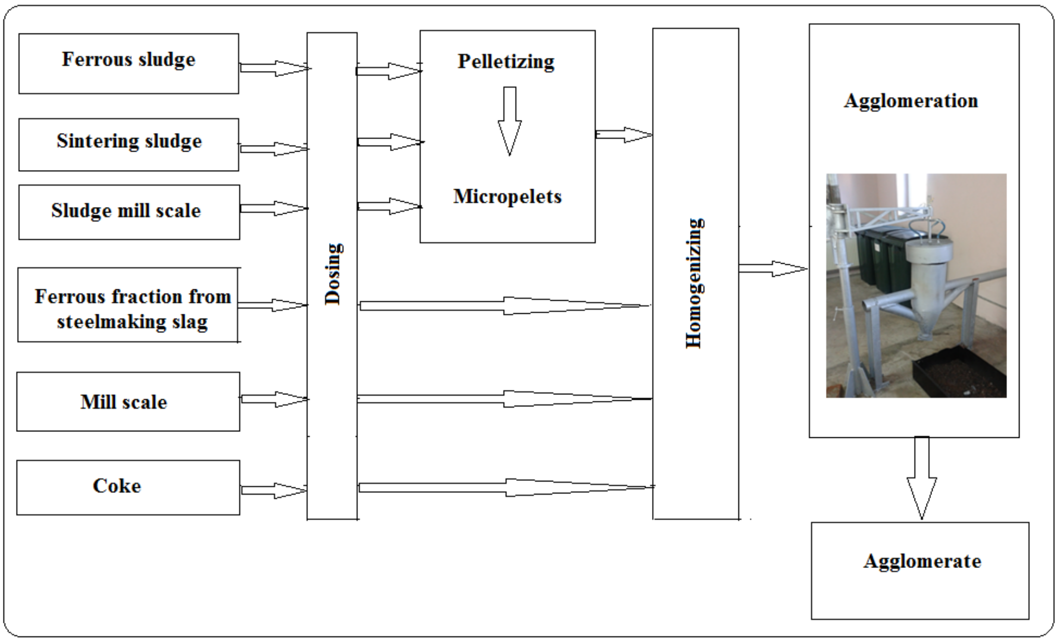


Fig.6. The technologic flux of obtaining agglomerate

The protective bed consisted of pellets with a grain size of more than 12 mm and was loaded directly on the installation grid. During the experiments, the height of the protective bed was between 30-40 mm. The protective bed improves the agglomeration conditions by protecting the grate against high temperatures, reduces the entrainment of small fractions of the load under the grate, and allows the agglomeration process to be driven to the last layer, without the agglomerate sticking to the grate bars. The protective bed also prevents the free section between the grill bars from being clogged with a small material, thus improving the suction regime.

The raw batch is placed in the agglomeration cup, in which the protective layer was initially inserted on the grill, distributed as evenly as possible on the section of the installation and packed evenly. Turn on the burner, fold the system cover over the batch, during which time the extractor (fan) is switched on and leave it on for an average of 60 seconds to light the coke, then fold it off the cup and switch it off. As a result of the expiration of air through the layer of material, the coke ignites and the sintering front advances from the surface of the load to the grate.

Table 6

Component of experimental recipes

Component (%)	R1	R2
Sludge mill scale	17	17
Sintering sludge	8	17
Ferrous sludge	17	17
Mill scale	8	0
Ferrous fraction from steelmaking slag	33	38
Coke	8	8
Electrode scrap	8	3

The agglomeration process begins in the surface layer when the fuel in the charge ignites. Further, air is drawn from the atmosphere through the surface layer of the agglomerate and the agglomeration process is continued. The combustion temperature in the surface layer reaches 1000-1200grC, and subsequently as the combustion and agglomeration area decreases, the temperature gradually increases up to 1300-1400grC.

3. Result and discussion

Aspects during the experiments are shown in Fig. 7. Depending on the excess coke, in the sintering layer the reactions of reduction of iron oxides from the upper to the lower form and, in a certain proportion to the metallic iron, develop.

During the agglomeration process, the evolution of the depression, the temperature and the reduction of the height of the agglomeration layer were followed. After finishing the agglomeration process, the agglomerate was evacuated and allowed to cool, after which the qualitative characteristics presented in table 7 were determined.

Table 7

Chemical composition of experimental samples

Recipes	Fe [%]	Fe_2O_3 [%]	SiO_2 [%]	Al_2O_3 [%]	CaO [%]	MgO [%]	MnO [%]	Cr_2O_3 [%]	Na_2O [%]	P_2O_5 [%]	Other oxides [%]
R1	28.40	40.57	24.37	5.49	16.87	5.56	2.99	0.44	0.65	0.50	2.56
R2	46.12	65,88	13,85	4.95	8.18	3.27	1.46	0.17	0.44	0.24	1,56

R_1 - CaO/SiO_2=0,69; R_2 - CaO/SiO_2=0,62

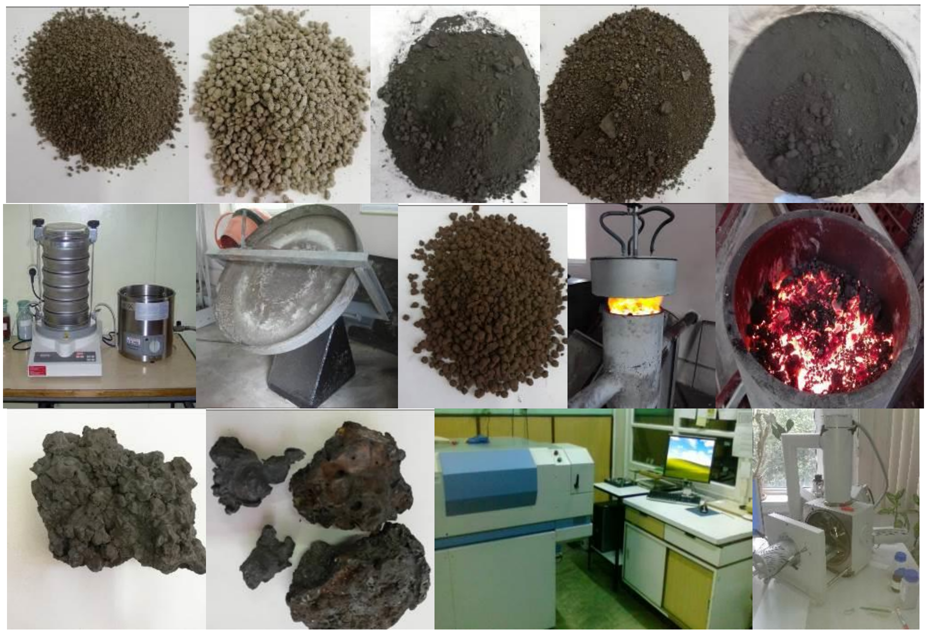


Fig.7 Aspects during laboratory experiments

The quality of the agglomerate produced is determined in terms of chemical composition, particle size and mechanical strength. The chemical composition of the agglomerate is determined in order to know the Fe, Mn content and basicity. The Fe content in the experimental agglomerate has values between 38-46%, depending on the balance of raw materials.

The granulation of the agglomerate is determined by sieving and is represented by the percentage content of the fraction 6-10 mm, from the sorted agglomerate which must not exceed 22%. The mechanical strength was determined with the help of the MICUM drum. The mechanical strength is given by the percentage content of the particle size fraction 0-6.3 mm.

The assessment of the quality of the agglomerate from a physical-mechanical point of view is made according to the content in the particle size fraction 6 - 10 mm and the mechanical resistance. The experimental agglomerate has a mechanical strength of 14% and a fraction of 6-10 mm is 12%. The obtained agglomerate falls into class C of medium quality. The quality indicators are mainly related to the chemical composition, the physical condition of the chipboard pieces, their mechanical strength, as well as the hot behavior. The porosity of the agglomerate varies in the limits of 40-60%.

4. Conclusions

From the analysis of the qualitative characteristics (chemical and granulometric composition) of the analyzed waste results the following:

- Powdery and small ferrous waste results from the steel industry and mostly it is stored;

- The analyzed waste contained different iron content from 19.35% (steel slag) to 66.54% (ferrous sludge);

- The agglomeration sludge, in addition to iron, is the main element, it also has a high carbon content of 22.04%;

- From the point of view of the chemical and granulometric composition, the waste can be recovered by recycling, the choice of technology took into account all the qualitative characteristics as well as the destination of the resulting product;

- Waste recovery by conventional processes (agglomeration) can provide products with reduced advanced iron oxides.

The analysis of the capitalization process and the experimental results shows the following conclusions:

- By processing the waste in the form of agglomerate, a by-product usable in the loading of furnaces for the production of metal alloys was obtained;

- considering the fact that the recipes contained 33-38% of the small ferrous fraction below 5 mm of the steel slag was obtained agglomerated with an iron content of 38-46%;

- By using in recipes, in addition to metallurgical slag, various quantities of sludge resulting from the steel industry, a by-product containing iron and iron-containing elements in steel is obtained, recovering these elements in the steelmaking process;

- The parameters followed during the agglomeration process varied within normal limits, observing a decrease of the depression with the increase of the addition of coke as a result of a less dense agglomeration. Also, as the proportion of coke increases, the temperature under the grill increases and the height of the agglomerate layer in the installation decreases.

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