HARNESSING THE FERROUS SLUDGE RESULTING FROM STEEL INDUSTRY IN THE CONTEXT OF THE CIRCULAR ECONOMY

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The global steel industry faces a number of challenges related to the production and processing of raw materials, namely price volatility and supply chain vulnerability. In recent years there has been a deterioration in the quality of raw materials, affecting environmental efficiency and performance. The steel industry must meet increasingly stringent environmental standards, which is achieved through the development of new technologies and techniques. The paper presents the laboratory research carried out on the possibilities of recovery by agglomeration of ferrous sludges resulting from the steel industry and the results obtained. Steel ferrous slavery is processed by agglomeration and the resulting by-product is used as a raw material in the production of steel, laboratory tests being carried out in an induction furnace.

Keywords: pulverous ferrous waste, steel, circular economy, environment

1. Introduction

The steel industry faces problems that are related to raw material and energy resources and environmental requirements. The development of this sector is conditional on solving the problems arising from the industry-environment relationship being strictly directed on pollution control and protection of natural and energy resources. The ecological concept applied to the steel industry involves the development of closed loop production technology flows [1]. Waste from the steel industry due to the possibilities of recovery through recycling or/and re-use, falls into the category of by-products, which together with scrap are sources of ferrous raw materials. The superior recovery of steel waste is an important problem, as its transformation into by-products leads to a rational

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exploitation of raw material and energy resources, thus ensuring both the needs of human society and protection of the environment [2]. In the steel industry, in addition to the main manufacturing product, small and powdery wastes, containing carbon, iron, alloying elements and useful components for the formation and correction of the chemical composition of slag, are produced. Resulting waste: dust and shams in the agglomeration, blast furnace and steel works sectors; mill scale and slain of the mill scale; iron filings; ferrous and slag [3]. Waste recovery technologies should be promoted to ensure both rigorous waste management and the reduction at source of the quantity and harmfulness of waste produced. The global development strategy of the metallurgical industry is to develop high-performance technologies to reduce emissions and increase the recovery and recycling yields of by-products. The package regarding the EU circular economy includes legislative proposals on waste, with long-term objectives for reducing its storage and increasing recycling and re-use [1, 4]. The Action Plan supports the circular economy at every stage of the value chain: production, consumption, and manufacturing, waste management and secondary raw materials that are reintroduced into the economy.

Benefits of the circular economy: reducing energy and resource consumption and carbon dioxide levels [5, 6]. For the application of the concepts of sustainable development, a balance should be struck between the volume of raw materials used and the volume of waste that can be recovered, with positive effects on reducing pollution. Particular attention should be paid to the technologies for processing recoverable waste, resulting in current manufacturing and stored flows. The steel industry is an integral part of the global circular economy that promotes zero waste, reduces the amount of materials used and encourages the reuse and recycling of materials [7-9].

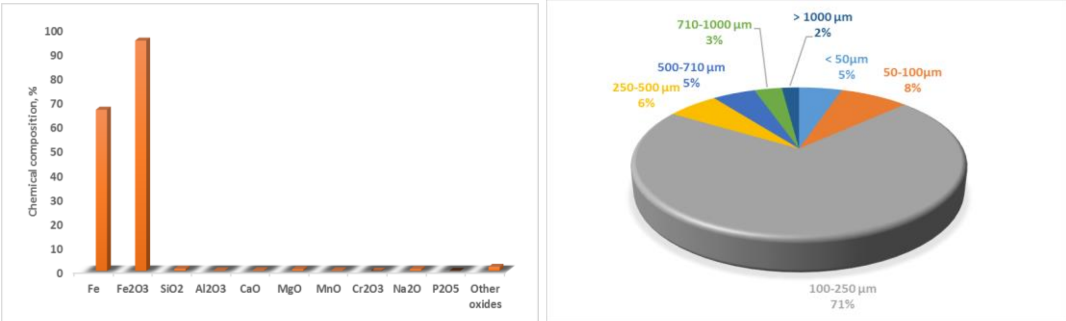
Today, the global steel industry uses about 2 billion tonnes of iron ore, 1 billion tonnes of coking coal and 575 million tonnes of recycled steel to produce about 1.7 billion tonnes of crude steel. Recycled steel is one of the most important raw materials in the steel industry [10-12]. The main solid wastes resulting from the development of steel are: slag, electrofilter dust and shams. The resulting waste quantities, depending on the development technological flow, are [13, 14]: 200kg waste/t steel to the technological flow which uses as an aggregate of the electric arc furnace (EAF) and 400kg of waste/t steel to the technological flow which uses as aggregate the oxygen converter (BF-BOF).

2. Experiments in the laboratory phase

For the exploiting and reintroduction in the economic circuit the ferrous sludges, resulted from the steel industry there are presented experimental technologies, in the laboratory phase, for the establishment of material solutions, compatible with the recovery of powdery and small ferrous waste, by producing agglomerates used as raw material in steel-making aggregates.

The sludge subjected to laboratory phase experimentation are: ferrous sludge, mill scale sludge and agglomeration-furnace sludge. As fuel it was used for the small coke agglomeration process.

Samples were taken from the shams tested for chemical and granulometric analysis. Their chemical and granulometric composition being shown in figures 1-3. Analysing the chemical and granulometric composition of the sludge, the technology of processing them by agglomeration was established in the agglomeration box. The sludge samples were subjected to the pelletization operation (a process similar to that of the homogenization drum on the agglomeration industrial stream) and the obtained micropellets were used for the formation of raw agglomeration charge. The technological flow of processing of steel ferrous ferrets is presented in figure 4.



a. b.

Fig. 1. Ferrous sludge analysis: a) chemical composition and b) granulometric classes

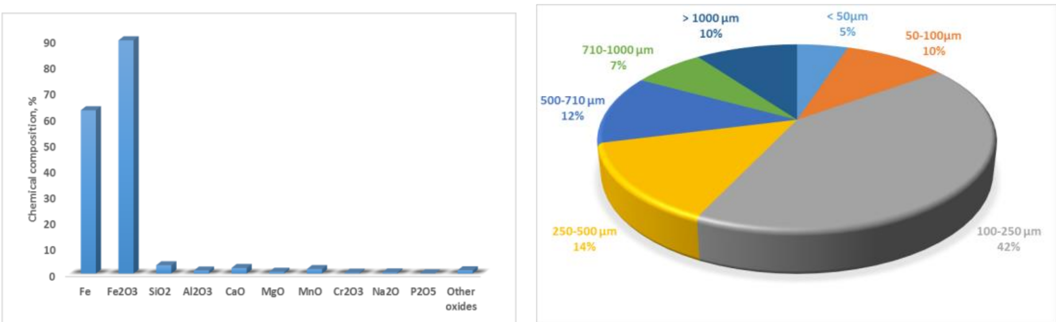


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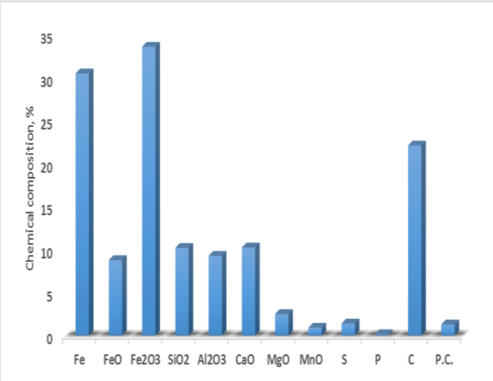
Fig. 2. Sludge mill scale analysis: a) chemical composition and b) granulometric classes

The composition of the experimental recipe is shown in Table 1. The small coke with 0,5-3,0 mm granulation used in the agglomeration barge must be as homogeneous as possible mixed with the ferrous materials subject to agglomeration. With regard to the addition of small coke (granulation and proportion) the role of both heat and reducer was considered. No addition of lime (or limestone) has been made because according to the resulting slag load calculation it is not acidic (the oven lining is basic).



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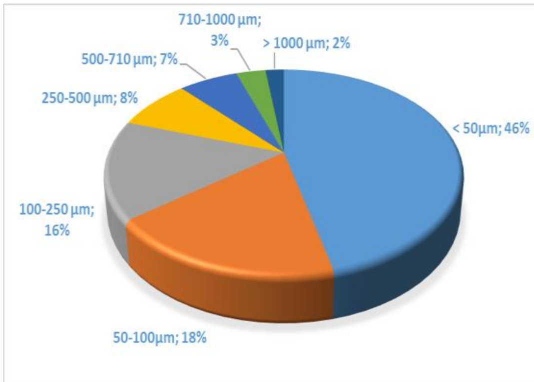

b.

Fig. 3. Agglomeration-furnace sludge analysis:
a) chemical composition and b) granulometric classes

The products obtained and the aspects during laboratory experiments are shown in figure 5. For the agglomerate obtained, the qualitative characteristics have been determined and its chemical composition is shown in table 2.

The experimental agglomerate obtained was still used for steel development. Experiments were carried out in an induction furnace of 10 kg capacity, with the crucible volume of 1.5 dm^3 and basic lining. In experiments for the formation of the metal bath we used steel waste in the amount of 4.5 kg/ charge and 3.5 kg agglomerated/ charge, and for the correction of the chemical composition of the slag an addition consisting of: 0.35 kg lime/charge, 0.15 kg bentonite/charge, 0.15 kg fluoride and 0.45 kg of graphite (to reduce iron oxide from the agglomerate) 0.15kg silico-manganese and aluminium were used for deoxidation. The steel waste was loaded in the first phase in the furnace and when they were melted the bath was heated for 5 min, after which the steel sample was taken to determine the chemical composition, after which the experimental agglomerate and additions for the formation and correction of the chemical composition of the slag were added. Additions on crowded and materials for the formation of slag were carried out, in equal portions, as they melted. The steel load being clean, practically the resulting amount of slag is insignificant (after the steel melting on average we extracted an average of 200 g of slag). When melting was assessed to be complete, the temperature was measured and sample taken from the metal melt to determine the chemical composition.

Table 1

The component of the experimental recipe

Component	Proportion, (%)
Ferrous sludge	50
Sludge mill scale	20
Agglomeration-furnace sludge	10
Coke	10

Table 2

Chemical composition of experimental sample

Chemical composition, [%]												
Fe_2O_3	Fe_{met}	Fe_{tot}	SiO_2	CaO	Na_2O	MnO	Al_2O_3	MgO	ZnO	S	C	Other oxides
49.12	37.93	72.31	5.27	1.96	1.18	0.71	0.68	0.43	0.18	0.39	0.15	2.0

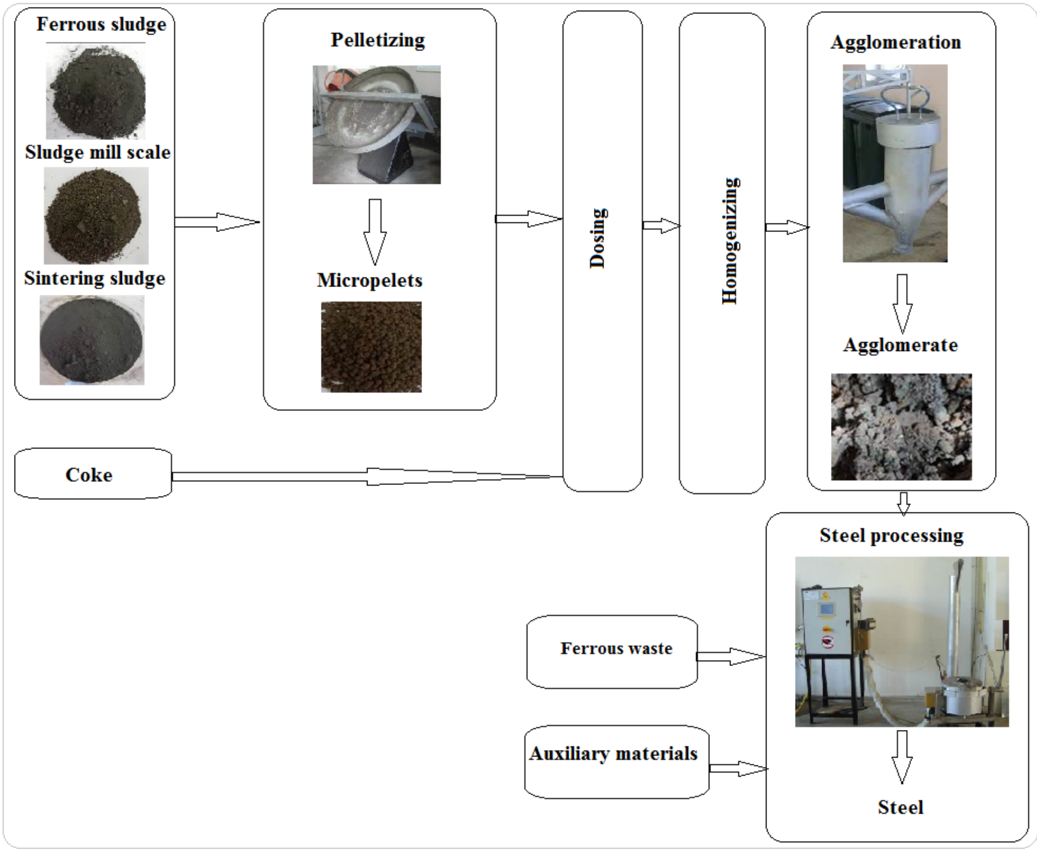

Fig. 4. Technological flow of waste processing

Fig. 5. Aspects during laboratory experiments

After the melting of the entire load, the melt was maintained in the oven for 5 minutes for thermal homogenization and for fluidization of slag, after which both the metal melt and the slag pour the graphite shell. After cooling they were weighed, together with the extracted slag, for the purpose of carrying out the material balance and also the chemical composition of steel and slag was determined.

3. Result and discussion

The processing of the sludge resulting from the steel industry has led to an experimental agglomerate. Figure 6 shows the busy result and its macrostructure made using the digital stereomicroscope model 520SZM-D.

The resulting by-product is the raw material for the development of a steel sham alongside ferrous steel waste. The chemical composition of the steel samples taken when the metal waste is melted and after the experimental agglomeration has melted is shown in table 3 and table 4. The chemical composition of slag is shown in table 5.

Table 3

The chemical compositions for steel melting

Chemical composition, [%]					
C	Mn	Si	P	S	Fe
0.45	0.64	0.32	0.041	0.034	98.52

a. b.

Fig. 6. Experimental agglomerate: a) by-product and b) stereo-microscope image

Table 4

Final chemical composition of steel

Chemical composition, [%]					
C	Mn	Si	P	S	Fe
0.48	0.60	0.32	0.045	0.035	98.13

Table 5

Chemical composition of slag

Chemical composition, [%]									
CaO	SiO_2	Al_2O_3	MgO	CaF_2	FeO	MnO	P_2O_5	S	CaO/SiO_2
51.40	22.46	8.43	7.00	4.21	2.50	0.85	2.24	1.00	2,29

Based on the chemical compositions of the steel, the degree of iron recovery shown in table 6 has also been determined and the load balance, the results of laboratory analyses and technological calculations are presented in Table 7.

The degree of iron recovery is calculated with the relationship:

$$\eta_{Fe} = \frac{(Fe_{II} - Fe_{I})}{Fe_{agl}} \cdot 100 \quad (1)$$

where: η_{Fe} represents the recovery degree of the steel from the agglomerate;

$Fe_{I.}$- the iron quantity before the addition of the agglomerate;

$Fe_{II.}$- the quantity of iron from steel after the addition of the agglomerate.

Table 6

Charge review

Charge, kg					Melt, kg					Gases Dust, kg
Steel waste	Experimental agglomerate	Add 1	Add 2	Total	Steel I	Slag I	Steel II	Slag II	Total melt	
4.50	3.50	0.65	0.15	8.80	4.30	0.20	6.99	1.61	8.80	0.18

Table 7

Iron review

Iron, kg					$\eta_{rec.Fe}$, %
[1)]Fe_I	[2)]Fe_{II}	$Fe_{II} – Fe_I$	Fe_{agl}	Fe_{slag}	
4.44	6.85	2.41	2.53	0.023	95.27

Experimental agglomerates produced from powdery waste (sludge) containing iron/iron and carbon by combustion can be metalized, which allows their use as a component in the load of furnaces for the production of steels.

4. Conclusions

In the iron and steel industry, apart from the main product of manufacture, pulverized and shredded waste containing iron, carbon, alloying elements, iron and carbon as well as basic/acid oxides are produced continuously in appreciable quantities proportional to the production. The significant quantities generated, the negative environmental impact and the economic potential of useful components have required solutions for their recycling.

The paper presents solutions for the recovery of steel sludge by processing them and using them as a raw material in the production of ferrous alloys. The composition of the recipes can be determined according to the amount of pulverized and small waste that exists and the destination of the processed material. The experiments carried out have shown that powder and small waste containing iron (in this case more than 60 %), after pre-processing with a view to processing into large pieces, can be used in the cargo of steel kilns with scrap iron.

Agglomeration has been chosen in experiments as a pre-processing process for sludge (allows processing of a large range of waste on the one hand, and on the other hand relatively easily applied with reduced investment of the discontinuous process). The results obtained enable the technological flow of waste processing with high iron content to be determined in order to reduce/metallized agglomeration by a degree of metallization.

In conclusion, powdery and small waste can be used in current practice in the steel industry and research needs to be continued to establish the best processes, recovery technologies, both economically and environmentally.

Depending on the specific conditions of each steel unit, as well as the demand on the local market (variable in time) of each usable material, any waste may become by-product and any by-product may become waste. Making better use of iron and steel waste is an important problem, because turning it into by-products, hence economic goods, can lead to rational exploitation of raw materials and energy resources, thus ensuring both the needs of human society and environmental protection.

The preoccupation about respecting the legislative requirements and the need to harmonize processes during economic growth with a rational segmentation of material and energetical resources, must lead to the capitalization of waste through technologies that offer the optimal solution both economically and ecologically. The worldwide strategies of metallurgical developments consist in developing performant technologies in order to reduce emissions while also grow the capability of by-product recovery and recycling.

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