MANAGEMENT OF MATERIAL RESOURCES IN THE STEEL INDUSTRY

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In the steel industry, raw materials and the base of the materials are of significant importance; the production of metal alloys and the quality of semifinished products (sheets, blums, etc.) depend on the management of material flows (inputs-raw materials, auxiliaries, and outputs-residues / waste).

The paper analyses the material management activity within a steel company (steel mill) and identifies the degree of application of Best Available Techniques (BAT) related to steel production technology in electric arc furnace. Following the findings, the authors developed a series of recommendations and solutions according to the particularities of the management activity carried out within the analysed company.

Keywords: Best available techniques (BAT), material resource management, steel industry

1. Introduction

Within the steel industry, due to the processes of elaboration and processing of metal alloys (cast iron, steel), various wastes are generated in significant amounts. A problem is represented by production residues (slag, steel mill dust, slag, slurry, etc.), which in the specialised literature [1-4], are called small and powdery waste containing iron. They are frequently stored long-term in various locations (dumps, ponds), although they have an intrinsic value determined by their content in useful elements (Fe, C, etc.), which favours their processing and valorisation in industrial steel processes.

The problem of dumping steel waste in locations such as dumps and tailings ponds is very topical, with a global estimate of 400 million tons of waste generated annually, the steel industry in Romania generates in a single year a value of 4.8 million tons of waste [5].

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The amount of iron-containing industrial waste generated is directly influenced by the choice of the elaboration process (blast furnace, electric arc furnace, converter, electric induction furnace) and the demand for ferrous steel products (steel, cast iron).

Within the National Waste Management Strategy, waste management options were identified, adapted, and exemplified for steel industry, as follows [6]:

- *waste prevention by applying "clean technologies"* — in the steel industry waste prevention is impossible, you cannot produce without generating waste, although clean technologies are applied (gas and wastewater treatment);
- *minimising waste by implementing best practises in each waste-generating activity* — it is applied by reintroducing some waste (crusts, solidified metal, non-compliant products - scrap, etc.) within the streams in which they were produced, applying the concepts of circular and green economy;
- *recovery* — processing of small and powdery waste containing iron and its transformation into by-products (pellets, briquettes, agglomerate, iron sponge), which is subsequently recovered as secondary raw materials in the elaboration processes;
- *disposal* — long-term storage of small and powdery waste containing iron is not recommended in outdoor locations directly on the ground. The activity of disposal of industrial waste containing iron is possible through the concept of industrial symbiosis (waste from one industry can become raw materials for another industry), e.g., the deferrized fraction of steel mill slag can be used in the cement industry, the Zn content of steel mill dust can be used in the non-ferrous alloys industry (brass manufacturing).

In the process of managing waste from the steel industry, it is sufficient if the following options are strictly considered: **minimisation / elimination** of historical landfills by their **recovery** in the elaboration processes and recirculation of waste generated on current streams, respectively, their transformation into secondary raw materials.

Industrial pollution caused by the steel industry, especially in terms of landfills, can be reduced by applying management strategies focused on improving logistics material flows. Industrial steel waste should be considered valuable sources of materials, so that, through processing, it is transformed into by-products (secondary raw materials) destined for metal alloy production processes. Starting from this consideration, strategies specific to the various material flows existing within steel companies can be devised, thus contributing to the development, and ensuring of their own base of raw materials and materials.

Improving the waste management system can make significant contributions to the protection of environmental factors in terms of preserving natural resources, also leading to greater sustainability in the steel industry.

In the field of waste management, 3R (Reduce, Reuse, Recycle) and 4R (Reduce, Reuse, Recycle and Recover) [5,7], are management strategies that aim to minimise the amount of waste landfilled and promote sustainability. For the case of steel industry waste management from the steel industry, it is considered sufficient to focus on the **recycling** component that includes both the **reduction** and **reuse** components. Fig. 1 shows the developed concept.

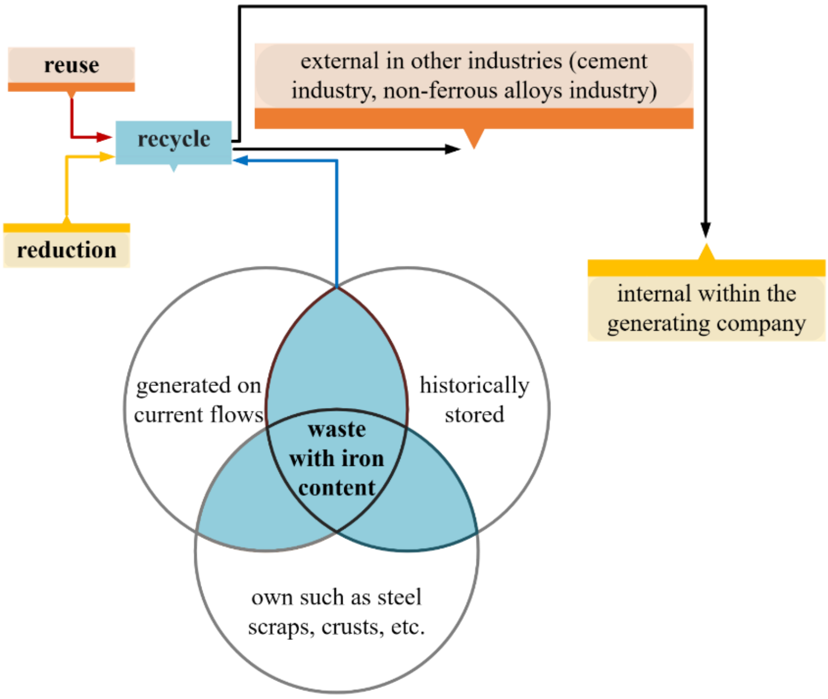

Fig. 1. 3R strategy applied to the process of managing steel industry waste

Worldwide, there is intense concern regarding finding solutions for the recovery of useful elements from steel waste, their use being determined by economic and environmental considerations aimed at closing and greening slag dumps, tailings ponds, etc. The main objective is to develop a sustainable system loop that can convert all valuable resources found in landfills into useful products [5].

Improvements to current steel waste, aimed at the recovery of useful elements from waste, contribute to the conservation of primary natural resources (iron ore).

Scrap metal recycling is vital to produce new steel products, which allows steel producers to save energy and conserve natural resources [8].

The electric arc furnace method (solid, metallic charge consisting exclusively of scrap or scrap metal and various by-products - iron sponge, pellets, briquettes, agglomerate obtained from small and powdered waste containing iron), is that which generates fewer residues in the environment than production based on primary resources (development in blast furnaces, oxygen converters) [9].

Regarding the management of material streams and waste generated in the steel industry, we mention that there are several recommendations provided in Best Available Techniques (BAT); steel companies must comply with the provisions contained in the BREFs related to BAT norms. In this paper, these techniques will be detailed, identifying, and analysed to understand how they are applied in a steel company equipped with an electric arc furnace.

2. Methodology

This paper presents the activity of a steel company, regarding the management of material resources, related to the process of elaboration of steel based on metalic waste (scrap metal), in the electric arc furnace EBT (Eccentric Bottom Tapping) (capacity 100t). The authors identify the BAT rules related to materials management applied within the company, highlight problematic aspects of the management process, and design a series of measures and recommendations.

Worldwide and nationally, the smelting of ferrous materials, such as scrap iron from steel mills (e.g., bar heads, shortcuts), waste from producers of steel products (e.g., machine builders) and downgraded scrap metal (e.g., products for which the normal service life has ended), is commonly carried out in electric arc furnaces (EAFs), which have come to play an increasingly important role in modern steel concepts [10].

Following the study of the literature [2,3,10-15] the main phases of the steel elaboration process were identified in the electric arc furnace EBT were identified, these are represented in Fig. 2. It should be mentioned that, in addition to these main phases, of specific importance are also the secondary phases that take place before the start of the elaboration process and after its completion, and which provide: handling and storage of raw materials; pot treatment to correct the chemical composition and achieve the optimum pouring temperature; slag handling; continuous casting.

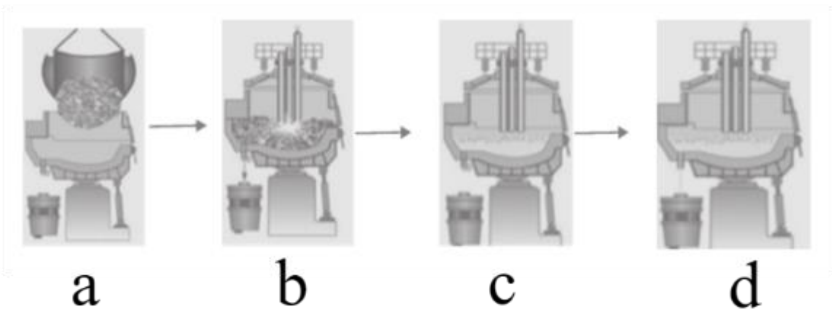

Fig. 2. Phases of the steelmaking process in the electric arc furnace EBT [11]

a - loading of the metallic load (raw and auxiliary materials), b - charge melting, c - oxidation and affinity (correction additions), d - steel exhaust

At the stage of loading preparation and composition, the desired steel quality of the developed material and the availability of raw materials must be considered.

Steel is evacuated from the furnace by opening the casting hole only when the chemical composition and temperature are satisfactory, with operations carried out, if necessary, to correct the chemical composition by adding additions such as ferroalloys. The elaboration must be appropriate, with respect to EBT technology (removal of slag from melting, foaming of slag, short affinities, use of insufflation lance, etc.). The elaboration of steel in electric arc furnaces EBT has gradually expanded within more steel plants that could refurbish their own production flows (blast furnace, oxygen converter).

According to the World Steel Association, by 2050, steel use is estimated to be 1.5 times higher than current levels to meet the needs of the population [16]. Table 1 indicates the quantities of materials used by a steel company during a year and shows the load composition of the electric arc furnace EBT.

Table 1

Balance of load of the steelmaking process in an electric arc furnace [13,15]

Name of materials		Realised consumption, [t/year]
1. Raw material		**331.258**
Scrap iron	Heavy scrap iron	175.505
	Light scrap iron	67.947
Own ferrous waste	Crusts	58.277
	Steel waste	29.529
Cast iron		6.727
2. Auxiliary materials		**23.238**
Dolomitic lime		1.002
Lime		16.243
Bauxite		576
Calcined coke		4.649
Graphite-filled wire		23
Electrodes		745
3.Composition correction additions (ferroalloys)		**4.397**
FeSi		818
FeMn		73
SiMn		2.664
FeCr		39
FeMo		22
FeV		41
FeNb		2
FeTi		4
Nickel briquettes		1

The quantities of auxiliary materials required are determined by their chemical compositions and metal charge, directly influencing the quality of the developed steel.

It is noted that the main raw material used by the company is scrap iron, which is positive in terms of energy savings and reduction of CO_2 emissions, but whose use generates a considerable risk in terms of the quality of the steel developed. We mention that scrap metal can be used in the steel industry only if it complies with certain quality conditions imposed by the European Union and which can be found in the report entitled "EU-27 Steel Scrap Specification".

Recently, the company has begun to apply measures to minimise specific consumption by reducing the use of the following materials in metal load: cast iron, FeCr, FeMo, and nickel briquettes [15].

In most of the elaboration operations of steel semifinished products (blues, sheets, etc.) production waste (slag, dust, mill scale, etc.) is constantly generated in significant quantities; they are useful in the steel industry in terms of content in useful elements (Fe, C).

Within the steel company, the following waste minimisation measures are applied [14]: their collection and storage in specially designated places; refractory waste is partially used in the technological process; steel mill dust is temporarily stored in a covered warehouse for external recovery; steel mill slag and refractory waste are temporarily stored in the heap for recovery.

Table 2 presents data on the amounts generated relative to the amounts recovered for three types of production waste. It should be mentioned that the data related to generation were collected for 12 months and at that time other significant quantities of these types of waste were in the landfill phase.

Table 2

Quantities of waste generated relative to the amounts recovered and remaining in the landfill
[13,15]

Name of the waste	Initial stock	Quantity generated	Quantity recovered	Quantity removed	Quantity remaining in storage
Steel mill dust	22352,19t	4353,36t	0	0	26705,55t
Mill scale sludge	1980t	430,00t	0	0	2410t
Refractory materials	492,11	388,39t	14,20t	-	773,71t

From the analysis of the data presented above, it is found that the waste called steel mill dust is stored in large quantities without being recovered internally. There is the possibility of internal capitalisation due to its high iron content, but it is the zinc content that limits its use.

Fig. 3 theoretically represents the material management activity within the steel company, carried out following the study of internal public documents [14,15].

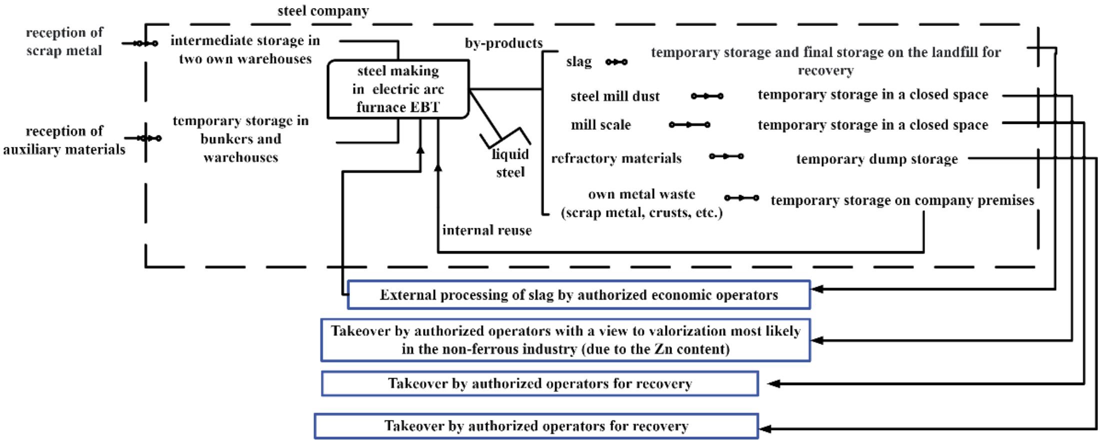

Fig. 3. Materials management within a steel manufacturing company

Part of the metal waste generated by the company (crusts, shots, shortcuts) is found to be used in the elaboration process as raw materials, while the vast majority of other waste is taken over by authorised operators for their recovery. We mention that we do not know how this waste is recovered by authorised operators and whether, through processing, the waste is transformed into by-products that are returned to the steel company as secondary raw materials. As evidenced by the data presented in Table 2, small and powdery iron containing wastes generated in the scrap steel production stream in the electric arc furnace EBT are frequently stored over a long period of time, the processing activity being low considering the speed and amounts of waste generated. For this reason, the authors also aim to identify the consistency with BAT techniques in the management of waste generated within the steel industry.

For solid waste generated within any steel company, the following techniques are considered BAT (in descending order of priority) [10]: minimising waste generation; minimising waste by recycling slag from the electric arc furnace and dust from flue gas treatment; depending on local conditions, steel mill dust can be recycled in the electric arc furnace to achieve a Zn enrichment of up to 30%; dust resulting from treatment, with a zinc content of more than 15%, can be used in the non-ferrous metal industry.

Based on the above and following the reference study [10], BAT techniques applied within the steel company where steel is developed in the electric arc furnace EBT were identified, using ferrous waste (scrap iron and its own waste - crusts, bar heads, etc.) as raw material. Table 3 presents the synthesis of the techniques applied to the electric arc furnace EBT according to BAT, indicating which are and are not applied within the technological flow of the steel company.

Table 3

Comparison table of steel production technology in electric arc furnace according to BAT [10]

The area covered by BAT		Application	Comments and recommendations
Dust collection efficiency	combining direct extraction of waste gases (4th or 2nd hole) with hood systems	YES (4th hole)	According to the norms in force, there are no exceedances of the parameter solid suspensions in the atmosphere)
	closing ovens in enclosures (“dog cage”) and hood systems	YES	The furnace is equipped with such a system
	total ventilation of the building	NO	-
Dedusting waste gases by using bag filters		YES	The resulting dust is stored in a disused hall
Reduction of solid particulate matter emissions from liquid steel treatment		NO	Secondary treatment is done in the pot
Minimisation of chlorinated organic compounds, in particular PCDD/F and PCB emissions	adequate post-combustion inside the flue gas exhaust pipe system, or in a separate post-combustion chamber, followed by rapid subsequent cooling	YES, in the combustion chamber additional, water-cooled	Gas cooling in air tube chillers
	injection of semi-coke powder into the exhaust pipe prior to filtering the bag filter	NO	No compound exceedances were found in the economic operator
Scrap iron preheating to recover physical heat from primary waste gases	Preheating part of the scrap metal;	NO	Construction of a tunnel with preheating of the load with heat given off by flue gases (there are references in the literature about such installations)
	preheating the entire amount of scrap metal.	NO	
Minimization of solid waste/by-products	minimising waste generation	NO	Correct completion of the stages of elaboration, refining, casting, and use of appropriate quality resources
	minimising waste by recycling furnace slags and filtration dust	NO	Create separate flows for the preparation of the ferrous fraction of slag and, respectively, for obtaining by-products by capitalising on steel mill dust
	minimising the amount of waste generated and	YES	The resulting slag is stored in the dump, by processing, the

	controlled storage of this waste		ferrous fraction is reused in the furnace, and the deferrized fraction is used in other industries.
Discharges into water	closed-loop water cooling systems for cooling furnace devices	YES	The water is cooled, treated, and recirculated.
	recycling casting cooling water as much as possible	YES	
	precipitation/sedimentation of solid suspensions;	YES	To recirculate the water under appropriate conditions, it is purified (solid substances, oils, etc.)
	removal of oils in separation tanks.	YES	

For solid waste, which cannot be avoided or recycled, the amount generated must be minimized, and if all possibilities of reduction / reuse have been exhausted, controlled disposal of these wastes is recommended until technologies that make this goal possible are identified [10].

In industrial practice, techniques to improve waste use are applied, in principle, to all BOF (Basic Oxygen Furnace) and EAF (electric arc furnace) plants where waste quality must be identified by analyzing its physical and chemical properties.

Table 4 presents an analysis that includes the identification of BAT material management techniques, which are or are not implemented by the steel company, and the presentation of how the activity is carried out, according to the implemented techniques.

Table 4

Identification of BAT techniques related to material management in the steel company and how they are applied [10,14,17] *****

BAT materials management techniques and requirements in a steel company	Verification of the application of BAT techniques within a steel company	Method of application within the analysed company
Techniques to improve waste use		
Specification of acceptance criteria for scrap purchase orders	✓	In the purchase contracts, the criteria accepted when purchasing scrap metal are specified.
Knowledge of the composition of waste by monitoring its origin and characterising its chemical composition	✓	The composition of scrap metal is monitored.
Possession of facilities for the reception and verification of	✓	The company owns a plant to process and check scrap metal

deliveries with waste exclusion procedures that are not suitable for use		entries. Non-compliant scrap metal is returned to the supplier.
Sorting of waste to minimise the risk of including hazardous or non-ferrous contaminants; this is normally done by the waste supplier	✓	A work procedure and work instructions have been implemented for the selection of scrap metal. The sorting of the scrap metal purchased is carried out by the supplier. External scrap iron is sorted to minimise the risk of including hazardous or non-ferrous contaminants.
Waste storage according to different criteria; storage with potential release of contaminants into the soil on impervious surfaces with a drainage and collection system or the application of a roof that can reduce the need for such a system	✓	Scrap metal is selectively stored on concrete platforms; the external warehouses are equipped with decanters for rainwater collected from the platforms.
Radioactivity control	✓	The radioactivity of scrap iron is checked by means of portals from automotive and railway weighing platforms, in the laboratory radioactivity control is carried out on each batch (melting sample and furnace slag).
Removal of mercury-containing components required by the End-of-Life Vehicles Directive (2000/53/EC) and the Waste Electrical and Electronic Equipment (WEEE) Directive (2002/96/EC)	✓	A procurement procedure has been implemented that allows avoiding mercury-containing components from end-of-life vehicles and visible waste from electrical and electronic equipment in scrap metal.
Possession of an operational and management plan	✓	Material balances are drawn up.
Techniques to reduce diffuse emissions generated by the storage, handling, transport, and dosing of materials		
Material delivery, storage, and recovery techniques		
The location of material discharge bunkers inside a building equipped with filtrated air extraction for dusty materials or bunkers should be provided with dust baffles and discharge grilles coupled to a dust extraction and cleaning system	▪	Bunkers for basic materials are open (outdoors), and the ones indoors are placed under hoods or under pressure.
Use of water sprays (recycled water) to suppress dust	€	It is not possible because it leads to wetting of the auxiliary materials.
If necessary, fitting storage bins with filter units to control dust	€	This is not the case.

Use of fully enclosed devices to recover from bins	€	
If necessary, landfill waste in areas with covered and hard surfaces to reduce the risk of soil contamination (using timely delivery to minimise yard size and therefore emissions)	✓	The waste is stored in an unpaved and uncovered landfill and in a covered concrete warehouse.
Minimizing inventory disruption	?	–
Height limitation and control of the general shape of stocks	?	–
Plant grass, shrubs, and other vegetation that covers the soil, which will minimise the removal of dust from these areas.	✓	On the surface of society there is rich vegetation.
Surface wetting using durable dust binding substances	✓	–
Coating the surface with tarpaulins or coatings (e.g., latex) to minimise dust lift	?	–
Application of the retention wall storage method to reduce exposed area	?	–
Slag handling and processing techniques		
Keep a stock of moist slag granules for handling and processing slags, as dry slag can cause dust	✓	Hot slag is sprinkled with water to cool it to a temperature, allowing it to be loaded onto the means of transport.
Use of closed slag crushing equipment with efficient extraction of dust emissions and bag filters.	✓	
Waste handling techniques		
Ensure that waste is stored in covered enclosures and / or concrete floors to minimise dust lifting caused by vehicle movements	✓	The waste is collected and stored separately in specially designated places.
Techniques to consider during the transportation of materials		
The transport roads must be concreted or paved to minimise the generation of dust clouds during the transport of materials and the cleaning of the roads.	✓	The roads that make up the internal motor transport network are paved or concrete. Dusty roads in the internal car transport network can be sprayed with the help of a special vehicle from the formation of the own fire brigade.
Restriction of vehicles on designated routes through fences, ditches, or banks of recycled slag	✓	The entry of vehicles into internal roads cannot be achieved through recycled slag fences, ditches, or recycled slag.

Damping of dusty tracks by water spraying, e.g., in slag handling operations	✓	The roads in the internal car transport network can be sprayed by the truck in the carriage of its own fire brigade.
Ensure that transport vehicles are not overloaded to prevent spillage	✓	It is ensured that the vehicles are not too full, preventing any loss
Ensure that transport vehicles are covered to protect transported material	✓	The means of transport are covered with a tarpaulin, as appropriate.
Minimising the number of relocations	✓	Measures are taken to minimise the number of transfers.
Use of closed conveyors	✓	Closed conveyors are used
Use of tubular conveyors, if possible, to minimise material losses through changes in direction between sites, usually provided by evacuating materials from one belt to another	€	This is not the case. The organisation operates in a small area.
Good-practise techniques for molten metal transfer and pot handling	✓	Good-practise techniques are used for molten metal transfer and pot handling.
Dedusting conveyor transfer points	?	–

* Legend: ✓ the application of the technique has been found; ? it is not known exactly how the technique was applied; ■ the technique is applied, but in an adapted form; □ the technique is not suitable for the company's activity

The environmental benefits generated by the application of techniques to improve waste use, which is also the case for the steel company whose activity was presented, are directly determined by the knowledge of the quality of the waste, increasing the possibility of anticipating unexpected emissions [17]. It is recommended to place a spray installation with recirculated water near small and powdery materials bunkers to retain particles in the air on the ground.

From an economic point of view, internal waste recycling in steel companies can lead to cost savings and increased steel production, which would result in a reduced amount of scrap metal purchased and a higher rate of return.

Most of the techniques mentioned in Tables 3 and 4 can contribute to increasing steel production, reducing costs (reducing energy consumption), and reducing environmental impact (reducing emissions), which are the main motivation for their implementation. The application of BAT materials management techniques is a common practise in all developed countries for plants such as an electric arc furnace or an oxygen converter.

3. Identifying solutions to improve materials management

It is considered that all waste generated by the steel industry, which has an intrinsic value determined by the content of useful elements (Fe, C, Zn, etc.), should be recovered, unless this is technically or economically impossible.

A substantial part of the materials are currently landfilled, so it is imperative to develop new recovery / recycling techniques and new transaction markets for those by-products / products.

The company that generates unused and landfill the waste should partner with companies specialised in the recovery of production waste come from the steel industry (waste with high iron content), using one or more processing processes (pelletizing, briquetting, agglomeration, and direct reduction).

As a proposal to reduce the dust resulting from bunkers for unloading auxiliary materials (lime, dolomite), would be the construction of a hall with road access (for unloading machines into existing bunkers), a hall in which exhausters would also be installed to capture the dust resulting from discharge.

Products made from waste processing (pellets, briquettes, agglomerate, iron sponge) can then be delivered to the steel company to be used as secondary raw materials in the load of the production unit (electric arc furnace EBT, induction electric furnace, oxygen converter) or to any other interested beneficiary.

Based on the analysis carried out on the waste management activity generated by the steel company, in Fig. 4 the current type of partnership, based on which, the authors developed proposals for partnerships between the main topics of interest regarding the recovery of small and powdery waste with iron content, with the aim of reintegration into the steel industry as secondary raw materials, applying the concepts of circularity and closed recovery loop.

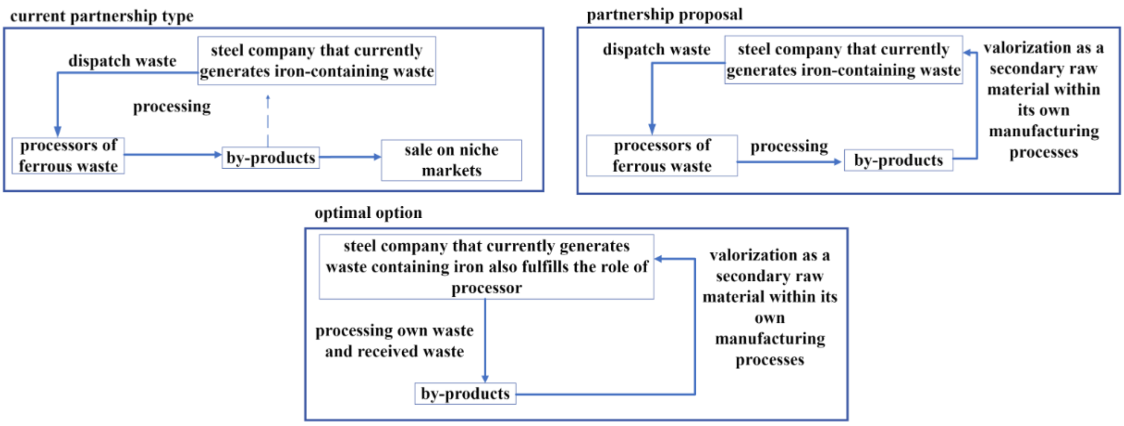

Fig. 4. Proposals for ways and partnerships that can be applied within any steel company, to recover iron-containing waste

It is considered more beneficial if the steel company fulfils the role of both processor and valorizer. It is recommended to develop and implement a processing flow (pelletizing and briquetting – require less investment, agglomeration – requires higher investments, but also the benefits are more substantial) in which most of the iron-containing waste mentioned in the paper can be processed and recovered within its own manufacturing flows.

Depending on the specifics of the type of waste and following the analysis of the activity of the steel company concerned in this paper but also of the reference study [18], the authors recommend the following actions to improve waste management within any steel company:

- Slag:
  - processing to separate the ferrous fraction from the non-ferrous fraction (it is practised within the steel company whose activity was analysed);
  - proposal to improve the current situation, respectively: the ferrous fraction recovered in the electric arc furnace as raw material (it is practiced within the steel company whose activity has been analysed); non-ferrous fraction sold to road and highway construction companies, cement industry, etc.
- Steel mill dust: internal recycling, processing to increase size for use in electric arc furnace load if the waste is viable in terms of zinc content (low content, less than 15%); internal processing, zinc enrichment, and sale to the non-ferrous industry.
- Mill scale: internal recycling, processing to increase size for use in electric arc furnace load (briquetting processing).
- Refractory materials: search for cost-effective opportunities to recover materials for internal reuse/recycling, otherwise neutralisation and landfilling (internal recycling of these types of materials is practiced within the steel company whose activity was analysed).

4. Conclusions

Worldwide, the manufacturing of steel products, in this case, steel developed in an electric arc furnace, must be consistent with the Best Available Techniques (BAT). In this paper, BAT techniques related to steel production technology in an electric arc furnace were identified within the steel mill whose material resource management activity was studied were identified. Following the findings, the authors developed a series of observations and recommendations on the implementation / application of these techniques that can be valid for the activity of other companies in the field.

The company applies BAT techniques to improve the use of generated waste but does not recover it internally except for the ferrous fraction of slag, refractory waste, and crusts, bar heads, and other waste from the processing processes of semifinished products.

Following the findings, the company recommends alternative solutions to improve the management activity in relation to raw materials and materials, with respect to BAT techniques related to steel production and the orientation toward the application of management strategies (3R, 4R), of circular, green economy concepts and closed-loop recycling, so that waste is introduced into the economic circuit and generates added value.

Regarding the processes and ways in which iron-containing steel waste can be processed and recovered, generated in current flows, as well as those stored historically, mentioned previously, we specify that the decision process regarding the choice of recovery technology is directly influenced by the physical, chemical, and mineralogical characteristics of the waste.

Identification of optimal technology for the recovery of waste generated within the company whose materials management activity was analysed, to use the by-products obtained exclusively in the process of developing electric arc steel, represents a future research direction that can be intermediated by carrying out cost-benefit analysis based on the particularities of the materials management activity. The purpose of this analysis is to increase the efficiency of waste use in the production process and implicitly to reduce the pollution caused by its landfilling activity. A future research direction is also represented by establishing connections / relationships between the subjects of partnership proposals and the ways of carrying out processing-transport-valorisation activities.

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