ISSN 0543-5846
METABK 59(1) 77-80 (2020)
UDC – UDK 669.18:669.14.002.68:502.72:621.762=111

ENVIRONMENTALLY RESPONSIBLE POLICY OF WASTES IN STEEL INDUSTRY

Received – Primljeno: 2019-06-28
Accepted – Prihvaćeno: 2019-08-31
Preliminary Note – Prethodno priopćenje

The problem of natural environment pollution, due to the increase in industrial activity, is of interest to an increasing number of countries around the world. The main purpose of waste policy should be the recycling of valuable raw materials, and thus the protection of the natural environment. The steel industry is an industry in which, alongside of mining and energetics, large amounts of waste are generated. These wastes in the EU are classified as thermal wastes and hazardous wastes. New technologies are being developed in many countries to reduce the amount of waste deposited. This study presents the results of research of iron-containing wastes in terms of their environmental impact in the case of storage, the possibility of iron recycling through the process of reducing iron oxides and the metallisation grades of selected wastes. The conducted research indicates the directions of waste management friendly to the natural environment.

Key words: steel production, metallurgical wastes, environment, dust, sludge

INTRODUCTION

With the increase of the population on Earth and the development of industry, environment pollution is increasing. The development of cities, economic human activities, industrial centres causes more and more harmful substances to enter the environment. The environment is polluted to the greatest extent by industrial emissions and wastes.

Until now, steel is a structural material that maintains its leading position. Therefore, metallurgy and foundry industry belong to branches of the economy, which market share is significant. In the total metal consumption, the share of steel and cast steel is over 92 %. Unfortunately, this industry generates significant amounts of wastes, including these containing iron. An increasing amount of this waste is being recycled, but some of it is stored. The article presents the results of investigations of iron-containing wastes in terms of their impact on the environment in case of storage, the possibility of iron recycling through the process of reducing iron oxides and the metallisation grades of selected wastes.

WASTE MANAGEMENT

The term "waste" - in accordance with the requirements of the European Union - covers any substance or object which holder (manufacturer) gets rid of, intends to get rid of or to which he is required to get rid of [1]. The steel industry is an industry in which, apart from mining and energy, the largest amounts of waste are generated. These are above all:

– sinter dust and sludge generated in the sinter production process,
– sludges created as a result of wet cleaning of blast furnace and converter gases,
– steel dust from the process of dry dedusting of electric arc furnaces,
– mill scale,
– dust and sludge generated as a result of cleaning iron and steel cast,
– blast furnace and steelmaking slags [2,3].

In accordance to the legal acts in force, the waste holder is obliged, first of all, to prevent the generation of waste, and then - to prepare for the re-use of waste, the occurrence of which has not been prevented. The least desirable way to handle waste is its neutralisation in landfills.

The experience of the most advanced countries in environmental protection shows that the minimization of waste generated "at source", i.e. prevention of its generation, is the most effective strategy in waste management. In the steel industry, activities directed to the protection of the environment, and above all the air, bring the opposite effect. The use of increasingly efficient filters causes "catching" of larger amounts of dust produced, both in the production of sinters, crude steel, steel and cast steel as well as in the cleaning processes of castings. Waste from electric arc furnaces due to their physical and chemical properties is a very bothersome waste. For these wastes, there was proposed their development in non-metallurgical industry - as an addition in the production of artistic glass, household glass, building ceramics [4]. The proposed solutions do not solve the problem of all steel industry waste [5-8].

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RESULTS AND DISCUSSION

The research of iron-containing waste were carried out in the following stages:

I. Acquisition of iron-containing waste;
II. Analysis of the chemical composition of the obtained steel industry waste;
III. Defining the physical-chemical parameters that allow waste for landfill storage;
IV. Defining the optimal conditions for the reduction of iron oxides contained in wastes.
V. Study of the environmental impact of the obtained reduced material (sponge iron).

ACQUISITION OF IRON-CONTAINING WASTE

As part of the research, the following wastes were obtained: dust from electric steel and cast iron arc furnaces, grinding dust from castings, dust from grinding machines, dust from dust extraction grating, moulding sand dust, mill scale and steel mill scale (from current and deposited production), sludge steel and foundry (from current and deposited production).

ANALYSIS OF THE CHEMICAL COMPOSITION OF IRON-CONTAINING WASTES

The analysis of the chemical composition was the basis for the selection of wastes eligible for iron recycling processes (iron oxide reduction process). The basic qualifying factor was iron content above 40 % which corresponds to the Fe content in the siderite. Table 1 lists the iron content for the obtained steel industry waste.

Table 1 **The iron content in the examined steel industry waste [own research]**

Sample no	Waste	Fe content / % mass
1	Electric Arc Furnace dust – steel plant	38,11 – 42,77
2	Dust from dedusting electric furnaces - foundry	30,93 – 41,67
3	Dust from grinding casts	24,83 – 89,57
4	Dust from cleaners	18,99 – 86,40
5	Dust from dedusting the shock grating	10,30
6	Dust from moulding sands	3,70 – 7,83
7	Rolling mill scale	81,67 – 85,10
8	Steel scale	72,83 – 85,60
9	Scale deposited	83,67
10	Sludges from the foundry	2,0 – 24,13
11	Steel sludge	67,57 – 78,17
12	Sludges deposited	37,40 – 59,87

The process of reduction of iron oxides contained in steel industry waste have been qualified:

- in foundries - tested dusts from EAF dedusting in steelworks are characterised by a zinc content above 18 %, which disqualifies them as a batch material for steelmaking processes;
- grinding dust from castings - before the reduction process, non-metallic impurities (oil, emulsion) should be removed from the waste;
- dust from cleaners - the analysis of the chemical composition (iron content) is required every time, the iron content in the obtained dust varied very much;
- steel and rolling scale (both from current production and deposited) - non-metallic impurities (oil, emulsion) should be removed from the waste prior to the reduction process;
- steel slags (both from current production and deposited) - chemical analysis (iron content) is required every time, iron content in the sludge obtained was very diverse.

DETERMINATION OF PHYSICAL-CHEMICAL PARAMETERS THAT ALLOW WASTE FOR LANDFILL STORAGE

The assessment of physical-chemical parameters of the steel industry waste tested, in the case of storage, was carried out in accordance with the EU directives [9,10]. The tests were carried out in an accredited laboratory (AB 213) in the field of collection and testing of waste samples. In accordance with the guidelines of these directives, the tested wastes were evaluated in terms of the conditions that they must meet when they generate sewage to waters or ground, the content of substances particularly harmful to the aquatic environment and meeting the criteria for admission of waste for storage.

The tested iron-containing wastes do not exceed the maximum permissible values of substances particularly harmful to the aquatic environment, causing pollution of waters in concentrations requiring their elimination. In many of the tested wastes, however, there are substances that are particularly harmful to the aquatic environment, causing water pollution, which should be limited. The conducted research has shown that such waste most often does not meet the storage criteria on any landfill (inert waste, waste different than inert and hazardous, hazardous waste) or meet the criteria for hazardous waste landfills. These are:

- steel EAF dust and from foundry - are harmful to the aquatic environment and do not meet the criteria for any of the landfills;
- dust from foundry induction furnaces - they are harmful to the aquatic environment, conditionally they can be stored in a hazardous waste landfill;
- grinding dust from castings - they are harmful to the aquatic environment and do not meet the criteria for any of the landfills or can be conditionally stored in a hazardous waste landfill;
- dust from cleaners, from dedusting the shock grate and moulding sands - they are harmful to the aquatic environment and conditionally may be stored in other waste landfill than non-neutral;

- steel, rolling and deposited scale - they are harmful to the aquatic environment and conditionally can be stored in the neutral waste landfill;
- steel sludges and from the foundry - they are harmful to the aquatic environment and can be conditionally stored in the neutral waste landfill;
- sludges deposited - they are harmful to the aquatic environment and do not meet the criteria for any of the landfills.

DETERMINATION OF THE OPTIMAL CONDITIONS FOR THE REDUCTION OF IRON OXIDES CONTAINED IN WASTES.

The iron oxide reduction tests were aimed at assessing the so-called degree of metallization of steel waste containing iron. The degree of metallization is defined as the ratio of the metallic iron content to the total iron content in the sample: (Fe_{met} / Fe_{tot}) * 100 %. The research involved three different waste from the steel industry: dust from the dedusting of the electric foundry furnace, steel sludge and rolling mill scale. In the conducted research, the reduction process was carried out using carbon monoxide, the same gas product was CO_2. This is so called indirect reduction, which starts above the temperature of 572 ^{O}C, and at a temperature above 1 000 ^{O}C it goes directly into one or two-stage direct reduction. The temperatures of the process of reduction of waste materials were selected at the borderline between indirect and direct reduction – 950 ^{O}C and 1 050 ^{O}C.

Only for scale, metallisation level was obtained qualifying this waste as metal charge to EAF (91,6 %). The level of metallization of the remaining waste (67 % and 52 %) indicates that the waste, after the reduction process, can be used as an enriched batch, e.g. for the blast furnace process. The obtained results indicate that the reduction of iron oxides at temperatures on the borderline between indirect and direct reduction allows reaching a good level of metallization of the reduced materials.

Further investigations were only carried out for scale. The next stage of research concerned the influence of ambient temperature on the secondary oxidation of reduced scale (sponge iron). In the developed technology of iron-containing waste reduction, the reduced material should be protected against contact with the oxidizing atmosphere, cooled in a protective atmosphere.

Reductions of iron oxides, as in the previous stage of the research, were carried out using direct and indirect reduction with carbon monoxide at 850 °C, 950 °C and 1 050 °C. The iron reduced in the tested material was subjected to an oxidizing atmosphere. In order to be able to assess the effect of different conditions on secondary oxidation of iron, two different temperatures were adopted, up to which reduced cooling of the iron would be carried out: 300 °C, 350 °C and 400 °C. The research material (scale) was divided into two fractions

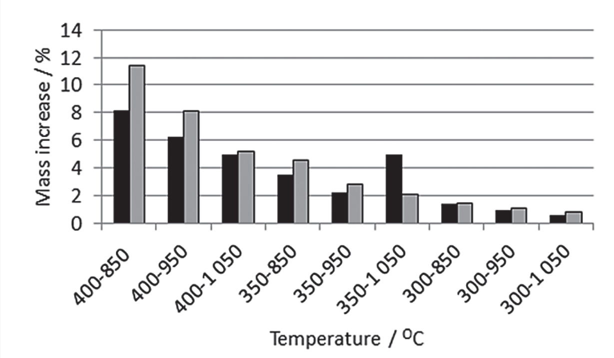

Figure 1 Mass increase during secondary oxidation of rolling scale at different temperatures, A - fraction collected in the metallurgical process, B - fraction powdered.

with different granularity: fraction A - with a grain size in which it is collected in the metallurgical process and fraction B - in ground form (powdered), in order to obtain a larger reaction surface during the experiment. Figure 1 shows the weight gain obtained during the secondary oxidation at 300 °C, 350 °C and 400 °C for the tested rolling scale previously reduced at 850 °C, 950 °C and 1 050 °C. The obtained results indicate that the mass increase due to the secondary oxidation of the reduced material decreases as the cooling temperature decreases - for both fractions with different grain size. The elaborated technology of iron-containing waste reduction should take into account the cooling of the reduced material (regardless of grain size) in a protective atmosphere, at least to the temperature of 300 °C.

STUDY OF THE ENVIRONMENTAL IMPACT OF REDUCED SCALE (SPONGE IRON)

The scale (sponge iron) obtained as a result of the reduction process has been evaluated in terms of the conditions that must be met in the event of sewage generation into waters or ground, the content of substances particularly harmful to the aquatic environment and meeting the criteria for its acceptance for storage.

Table 2 **Permissible limiting values of leaching for inert wastes as well as the leaching results of reduced scale / mg/l [own research]**

Pollution	The leaching result	Permissible limit value
Mercury	0,05	0,01
Molybdenum	1,50	0,50
Antimony	0,50	0,06

Reduced scale (spongy iron) is not harmful to the aquatic environment - in case when it generates sewage into waters or into the ground and does not contain substances particularly harmful to the aquatic environment that require their elimination or reduction. The obtained reduced scale (sponge iron) meets the criteria for landfill for other than inert waste and hazardous waste - the values for mercury, molybdenum and antimony were exceeded for landfills of inert waste. Table 2 presents the results of leaching of pollutants and acceptable limits of values for landfills for inert waste.

CONCLUSIONS

The main purpose of waste management should be to recycle valuable raw materials from them, thus protecting the natural environment and reducing the use of mineral resources and energy. Based on the research carried out, it was found that:

- The steel industry waste tested is characterized by a very diverse iron content - the minimum content qualifying waste for the recovery of iron is 20 % Fe;
- The tested iron-containing wastes do not exceed the maximum permissible values of substances particularly harmful to the aquatic environment, causing pollution of waters in concentrations requiring their elimination;
- Most of the tested wastes contain substances that are particularly harmful to the aquatic environment, causing water pollution, which should be limited - the steel industry waste tested is not environmentally friendly;
- Most of the investigated steel industry waste does not meet the storage criteria on any landfill (inert waste, non-inert and hazardous waste, hazardous waste) or meets conditional criteria, which is associated with the difficulties with landfilling the waste;
- Running a process of reduction of iron-containing wastes with carbon monoxide on the borderline between indirect and direct reduction (850 °C – 1 050 °C) allows obtaining a good and very good degree of metallisation of waste (over 90 %);
- The technology of iron-containing waste reduction should take into account the cooling of the reduced material in a protective atmosphere, at least to the temperature of 300 °C;
- Reduced scale (spongy iron) is not harmful to the aquatic environment and can be conditionally stored in a neutral waste landfill.
- The proposed experimental technology of reducing iron contained in the waste of the steel industry is pro-ecological, environmentally friendly, limiting the use of iron-containing deposits.

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Note: Kuczyńska-Gondzik A. is responsible for English language, Katowice, Poland