EXPERIMENTAL RESEARCHES ON BRIQUETTING AND MELTING OF FINE FERROUS WASTE

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Recovery of fine ferrous waste by briquetting them and melting these briquettes using electric arc furnaces or induction furnaces, is an efficient and economical solution for neutralization of industrial waste.

Pilot experiments were conducted in order to evaluate the behavior of briquettes (self- reducing, non-reducing and pre-reducing) during melting process in furnace and completing an iron chain reaction.

The experiments were made in pilot station ICEM using an air induction furnace with a five kilograms capacity with spinel refractory lining material.

Three charges were prepared, using three types of briquettes made of CEA powder from Arcelor Mittal Hunedoara workflow.

Keywords: briquetting, melting, ferrous waste

1. Introduction

Generally the briquettes made have porosity (lower than) < 10 % and their capacity range from 3.3 tons to 4.5 tons/m^3 the range of the grain size of the briquettes mixture includes an area of 4 mm, the fine ore fraction is at least 60-70 ηm 70 % and is produced with or without binder.

As it allows aggregating a wider particle size and lacking of hardening heat treatment, it allows iron ore briquettes to be produced in economic-efficient conditions compared to producing pellets.

Iron ore briquettes can be used in conventional technology to develop iron in the furnace, working iron in cupola or melting them in arc furnaces or induction furnaces.

Pilot experiments were conducted in order to evaluate the behavior of briquettes (self-reducing, non-reducing, and pre-reducing) during the process of melting in furnace and obtaining a heat balance of iron.

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2. Paper contents

Experiments were made in pilot station ICEM using an air induction furnace with a capacity of five Kg with a spinel refractory lining material (86% Al_2O_3, 12.5% MgO).

Three charges were made, using three types of briquettes, derived from CEA powder on Arcelor Mittal Hunedoara workflow. The furnace load is presented in table 1.[1,4]

Table 1

Structure of materials used in testing ferrous melting briquettes

Batch	Scrap, kg	Briquettes	
		kg	Component, state
1	2.35	2.35	Powder CEA +10% slag + 20% C, dry
2	3	3.0	Powder CEA 4% slag + 20% C, dry
3	2.7	3.2	Powder CEA + 15% C, pre -reduce

The process of working charges was conducted in accordance with technical instructions specific to this unit. This was done by melting the metal charge and after that briquettes were added in portions.

Portion of briquettes added was determined in such a manner so that it would not cause technical problems (spill slag) or accidents (splashes, explosions). There were no slag forming additions in order to determine, as accurately as possible, the quality of slag that is formed upon addition of briquettes so that to take technological measures to counteract the negative effect on the cupola, when adding the briquettes.

After preparation, the melt metal was molted into ingot, slag was molded to form Sholl metal type and after cooling they were weighed and chemically analyzed. The results from this first experiment are summarized in tables 2 – 4.

Table 2

Iron assimilation efficiency of briquettes

Charge	Chemical composition, %				
	G_{scrap}, kg	$G_{briquettes}$, kg	G_{ingot}, kg	$\eta_1 = (G_{lngot} - G_{scrap}) / G_{briquettes} \times 100,\%$	$\eta_2 = (G_{ingot} - G_{scrap}) / G_{iron\ briquette} \times 100,\%$
1	2.35	2.35	3.245	38.1	87.83
2	3	3.0	3.821	27.36	63.0
3	2.7	3.2	4.033	42.0	73.08

Table 3

Final chemical composition of the molten metal

Charge	Chemical composition, %				
	C	Mn	Si	S	P
1	2.64	1.573	0.64	0.615	0.100
2	2.24	0.865	0.182	0.563	0.058
3	2.35	0.179	0.041	0.805	0.053

Table.4

Chemical composition of the final slag

Charge	Chemical composition, %						
	CaO	SiO_2	FeO	MnO	Al_2O_3	MgO	CaO/SiO_2
1	28.50	26.18	1.27	5.81	24.64	10.99	1.08
2	25.72	28.1	5.74	10.26	21.1	9.84	0.91
3	24.03	20.55	22.39	11.56	13.82	7.56	1.168

The data presented reveal the following aspects:

1. The lowest efficiency was obtained in terms of using the briquettes obtained according to the recipe two (CEA powder 4% slag + 20% C, dry)

2. Almost same efficiencies were obtained when using briquettes obtained according to recipe one (CEA powder 10% slag + 20% C, dry) and reduced briquettes

3. The fact that it was obtained a lower efficiency when using reduced briquettes can be attributed to :

a. Using a higher content of reducer for those briquettes made after recipe one (20% C, compared to 15%)

b. Higher content of iron oxide in small briquettes, which can lead to further oxidation of iron in the absence of other element to protect iron.

c. Experimental process management - use of waste iron (C = 3.4 %, Mn 0.6 and 1.5 %)

d. Analysis of slag - high content of iron - oxide confirms the possibility of obtaining a lower efficiency of iron, in terms of using reduced briquettes in the absence of added carbon

4. In case of using non reduced briquettes the results are as follows:

a. Lowering the carbon content of the metal bath, some of the carbon used in palletizing switch to metal bath -can be an advantage in terms of processing the EBT, the heat input.

b. Desulphurization is negatively influenced beside other technological factors – slag basicity, compared ratio CaO/FeO; in all cases there is a massive assimilation of sulfur in the metal bath.

5. Regarding the melting behavior during briquette additions the results are as follows:

a. Increasing the amount of slag, explained by the reduction reaction that develops incompletely.

b. Release of CO, which ignites itself shortly after the addition and burns with red flame - charges one and two – see Fig. 1

c. The occurrence of bright and long-lasting flames, possibly due to removal of Zn - see Fig. 2, given the fact that the EBT powder from Hunedoara is rich in ZnO – more than 15%.

d. The resulting slag in the process is oxidized, acid, the highest charge amount resulting at the batch where there were introduced reduced briquettes. At this batch we can see tendency of the stopper to charge the furnace entrance, due to adhesion of acid slag to the lining.[3]

Fig. 1

Fig. 2

e. The chemical composition of resulting slag requires adopting specific measures for ensuring the development of refining process (dephosphorisation) in the primary unit development.

Calculating oxidations when melting the batch ***experiment A***:

In Table 5 presents the estimated oxidation proportion during melting, the resulting quantity of oxides and cast iron composition at the end of melting.

Table 5

Oxides, oxidations

Elements	C	Mn	Si	P
Oxides kg	0.093/CO	0.15/MnO	0.19/SiO_2	0.007/P_2O_5
Chemical composition of the melt, %	2. 01	~ 0.6	~1.75	~ 0.008

Calculation of necessary slag and lime quantity

For an approx. percentage of 5% slag resulting from the metallic charge results a necessary amount of 2 Kg of slag. The amount of lime related to a content of (CaO) in slag approx. 41% taking into account the calcium oxides (except CO) as well is ~ 0.8 Kg. Adding 0.2 Kg fluorine (for slag thinning) all resulting oxides (except CO) ~ 0.5 Kg (assuming they remain in the slag, thus ignoring the 'exchange' due to distribution reports) the remaining oxides from briquettes (~0.3 Kg) a quantity of slag of ~1.8 Kg results. The rest of 0.2 Kg necessary to reach 2 Kg of slag will be ensured by a further addition of briquettes. The total addition of reduced briquettes will therefore be in amount of 1.2 Kg (30 Kg/tone).

In table 6 is shown the estimated amount of oxides present in the slag and its estimated composition at the end of dephosphorisation. The amount of iron oxide is subtracted in order to reach the estimated slag quantity. For this slag composition the basicity index IB is 1.2.

Table 6

Slag chemical composition

Oxides	CaO	SiO_2	MnO	MgO	P_2O_5	Al_2O_3	FeO
Mass, kg	0,838	0,381	0,227	0,06	0,020	0,032	~ 0,442
Percent %	31,9	29,05	11,35	3,0	1,0	1,6	~ 22,1

The Experimental charge A characteristics :

- The batch metal load consisted of 4 Kg own cast iron waste which was melted in 18 minutes.
- After temperature measuring - 1540^0 C continued with a heating period for 8 minutes when temperature has reached 1575^0 C.
- PF 1 cast iron sample was drawn.
- Lime was adding in portion of 0,8 Kg (20Kg/tone) fluorite 0,2 Kg (5Kg/tone) and 1,2 Kg of briquettes (30Kg/tone), and the operation was completed in 6 minutes.
- After approx. 5 minutes (during which the slag became fluid) PZ1 slag sample was drawn.
- After a period in which the metal bath and the slag were heavily mixed with a metal bar for ~15 minutes, the temperature was measured (1570^0 C) and final PZ2 slag samples and final PF2 cast iron samples were drawn.[2]

Tables 7 and 8 shows the chemical composition of the cast iron and the slag after finishing the batch

Table 7

The chemical composition of cast iron %

Charge	sample	C	Mn	Si	P	S
A	PF1	2.45	0.35	1.26	0.016	0.34
	PF2	2.35	0.30	1.22	0.007	0.42

Table.8

The chemical composition of slag %

Charge	sample	CaO	SiO_2	MgO	MnO	P_2O_5	Al_2O_3	Fe_{total}	FeO
A	PZ1	24.3	21.6	3.8	4.2	0.15	10.4	25.3	32.4
	PZ2	22.9	20.4	4.3	3.7	0.16	12.1	26.9	34.5

Analyzing data from tables 7 and 8, results:

- Excepting of phosphorus, chemical elements oxidations during the melting process were higher than expected
- High contents of (FeO) show that the briquettes, once in metal bath show that iron oxidized too in the process in addition to other elements
- High content of (Al_2O_3) indicates an erosion of the refractory lining
- The content of (CaO) is smaller than that calculated due to the dilution mainly produced by large quantities of Al_2O_3 and FeO from the slag
- The degree of dephosphorisation was 56,25% given the conditions : a basicity index of approx. 1,15 and a ration CaO/SiO_2 of approx. 1

Experimental batch B:

Results based on first experimental batch A, we established some remedies:

- Reducing the amount of briquettes in order to reduce iron oxides from the slag;
- Increasing lime quantity in order to increase the content of CaO;
- Adjustment of the basicity ratio by adding sand (SiO_2 intake);
- Removing the slag resulted during the melting process.

Table 9 shows the estimated chemical composition of the metallic bath at the end of melting process and the end of the dephosphorisation process, the oxygen needed and resulting oxides.

Table 9

Chemical composition of metallic bath, needed oxygen, oxides resulting

Elements	C	Mn	Si	P
Chemical composition of metallic bath when melting, %	2.05	0.5	~ 0.05	~ 0.016
Final chemical composition, %	2.33	0.3	~ 0.02	-
Oxides, kg	0.018/CaO	0.01/MnO	0.025/SiO_2	0.015/P_2O_5

Adding the values obtained for the oxygen needed in table 9 results a quantity of 0.033 Kg of oxygen, which in equivalent briquettes, means a necessary reduced amount of briquettes of approx. 0.4 Kg. This briquettes quantity contributes with 0.034 Kg CaO, SiO_2 0.042 Kg, 0.02 Kg MgO, 0.011 Kg Al_2O_3 and 0.0022 Kg P_2O_5.

The amount of slag, lime and sand needed:

For a percent of 5% steel slag from the metal charge results a slag quantity of 2 Kg. The lime quantity related to a content (CaO) in slag of approx. 41%, taking also into account the calcium oxide given by the briquettes is ~0.85 Kg lime, but in order to prevent the dilution of (CaO), we increase the amount of lime up to 1.35 Kg.

In order to increase the content of (SiO_2) from the slag, we plan to add 0.2 Kg of foundry sand (9.9% SiO_2). If we add 0,2 Kg of fluorine (in order to liquefy the slag), the resulting oxides (except CO) of ~ 0,023 Kg, the remaining oxides brought by briquettes, approx. 0,11 kg there is a deficit of approx. 0.117 kg in order to reach the amount of 2 Kg. This quantity will be provided by supplementary adding of briquettes which means a total addition of briquettes ~0.52 Kg (13 Kg/tone). Table 10 presents the estimated amount of slag oxides and

its estimated composition at the end of dephosphorisation. For this slag composition the basicity index IB is 1.2 and the content of FeO is very high.

Table 10

Chemical composition

Elements	CaO	SiO_2	MnO	MgO	P_2O_5	Al_2O_3	FeO
Oxides, kg	1.29	0.28	0.01	0.025	0.018	0.013	~ 0.364
Chemical composition of slag, %	64.5	14.0	0.5	1.25	0.9	0.65	~ 18.2

Experimental batch B characteristics:

- Metal batch charge - 4 Kg own cast iron waste which was melted in 2 hours and 15 minutes
- The temperature was measured - 1575^0 C and it was removed from melting
- We drew PF1 cast iron sample
- We started lime adding in portions 1.35 Kg (33.75 Kg/tone), sand 0.2 Kg (5Kg/tone), fluorine 0.2Kg (5 Kg/tone) and 0.52 Kg briquettes (13 Kg/tone), the operation was completed in 12 minutes.
- After approx. 6 minutes (period in which the slag became fluid) we drew PZ1 slag sample
- After a period during which the metal bath and slag were heavily mixed with a metal bar ~ 14 minutes, the temperature was measured (1570^0 C) and PZ2 slag final sample and PF2 steel final samples were drawn

In tables 11 and 12 chemical composition of cast iron and slag are shown determined after batch ending.

Table 11

The chemical composition of the cast iron

No. of charge	Sample	C	Mn	Si	P	S
2	PF1	2.06	0.05	0.037	0.014	0.023
	PF2	2.32	0.04	0.010	0.005	0.022

Table 12

The chemical composition of slag

No. of charge	Sample	CaO	SiO_2	MgO	MnO	P_2O_5	Cr_2O_3	Al_2O_3	Fe_{total}	FeO
2	PZ1	40.76	14.19	3.19	3.18	0.29	0.81	10.64	13.91	16.15
	PZ2	39.10	12.62	4.84	3.68	0.20	0.69	16.95	17.26	19.15

3. Conclusions

By analyzing the data obtained from experimental researches we can draw the following conclusions:

- Effective oxidation of chemical elements during melting were almost the same as those expected;
- Excepting (Al_2O_3) all contents of oxides correspond to optimal composition of dephosphorant slag;
- High content of (Al_2O_3) are caused by the erosion of the refractory lining (given the industrial conditions there are no increases of Al_2O_3 increases , the refractory lining being magnetized)

The results obtained proved to that an addition of briquettes of approx. 15 Kg/tone metal charge is valid, at the same time achieving a good degree in dephosphorisation. Nevertheless, given the industrial conditions, upon the development in the cupola, differences may appear regarding the influence of briquettes addition on the processes that occur during melting.

The medium period of time for direct reduction of Fe_xO_y could have been determined by measuring the development period from the moment of introducing briquettes on a metal bath until complete stabilization of the melt where the slag composition of FeO is less than 2 - 3%.

The period of time thus determined is T_{melt} - 18-20 minutes. This period of time indicates the kinetic stage of the heating process and direct reduction.

Comparing to the melting conditions of the electric arc furnace, in cupola there is estimated an acceleration of processes due to indirect reduction of iron oxides with CO in gases.

R E F E R E N C E S

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