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RESEARCH REGARDING THE PHYSICAL AND CHEMICAL CHARACTERISTICS OF PRE-REDUCED IRON ORES AND THE ANALYSIS OF THE POSSIBILITIES OF THEIR USE IN THE IRON AND STEEL ELABORATING PROCESS

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ABSTRACT: Taking into consideration the complexity of the traditional iron and steel elaborating methods that demand the existence of ore preparation plants, cookery, etc. moreover the deficit of coking coals and iron scrap it is necessary to search new possibilities of modifying the existent technologies or replacing them by new methods. One option regarding this way represents the use of sponge iron obtained by direct reduction of iron ores or prepared into the iron and steel elaborating process. Considering the high materials and energy consumption and environment pollution in the traditional iron and steel elaborating methods our paper's aim is to analyze the opportunity and the possibilities of obtaining the iron and steel by non-conventional technologies. Our paper presents the results obtained from direct reducing of iron ores and our conclusions resulted from statistic analysis of obtained data by correlating the initial characteristics of the ores and qualitative characteristics of the pre-reduced product.
KEYWORDS: pre-reduced iron ores, iron sponge

❖ INTRODUCTION

Taking into consideration the complexity of the traditional iron and steel elaborating methods that demand the existence of ore preparation plants, cookery, etc. moreover the deficit of coking coals and iron scrap it is necessary to search new possibilities of modifying the existent technologies or replacing them by new methods. One potion this way represents the use of sponge iron obtained by direct reduction of iron ores or prepared into the iron and steel elaborating process.

Considering the high materials and energy consumption and environment pollution in the traditional iron and steel elaborating methods our paper's aim is to analyses the opportunity and the possibilities of obtaining the iron and steel by non-conventional technologies.

Our paper presents the results obtained from direct reducing of iron ores and our conclusions result from statistic analysis of obtained data by correlating the initial characteristics of the ores and qualitative characteristics of the pre-reduced product.

❖ OBTAINING PRE-REDUCED MATERIALS AND THEIR PHYSICAL AND CHEMICAL CHARACTERISTICS RESEARCH

We conducted the research in the laboratories of University "Politehnica" of Bucharest, the Ferrous Department. We established the experiments conditions starting from the initial granule size and composition of the ores, agglomerates and pellets. For the pre-reduced product, we established the reducing degree, the softening and melting temperature, the mechanical resistance and we found the correlation between the initial physical and chemical characteristics of the ores and the final characteristics of the pre-reduced material.

The ore's reduction is made in a reactor pipe with 140 mm diameter and 1000 mm length, made from stainless steel, which has in its inferior half chamotte spheres in order to heat the reducing gas. The ore sample is introduced into a net wire cylinder with the capacity of 1-3 kg of iron ore. The reactor pipe's heating is realized into a furnace having vertical bars 95) that can assure temperatures of about 80-100^{0}C (the transformer's power is 25 kVA). The reducing gas (H_2-99.5%) flows from the cylinder through the purifying vessels filled with mineral cotton, H_2SO_4 and $CaCl_2$. The hydrogen flow is measured and registered.

The determination of the removed oxygen quantity is made by continuous weighting of the reactor cylinder with the scales, and the temperature is measured with a platinum-platinum-rhodium couple. The methodology of the experiments is: the sample weigh: 1 kg, the sample's granule size, varies between 5 and 30 mm, temperature: 800-900^{o}C, the process period: 45 min, the specific H_2 flow: 0,7 l/min. g O_2 in the sample.

The pre-reduced material is mainly characterized by the following parameters:

- the reducing degree – represents the percentage of oxygen from the iron oxides being removed in reducing process:

$$RD=\frac{O_{2\,removed}}{O_{2\,initial}}\cdot 100\,[\%]\ , \qquad (1)$$

- the reducing velocity – represents the medium velocity of the oxygen removal from the iron oxides:

$$RV=\frac{O_{2removed}}{proc.period}[\%/\min.]\,, \qquad (2)$$

The pre-reduced sample (0, 5 kg and granule size over 5 mm) is maintained inside for 3 minutes (90 rotations). The crushed material is then screened on 5 mm and 1 mm screens, establishing the following parameters:

- the crushing index (C) – represents the 1-5 mm fraction (in percents);
- the dusting index (DI) – represents the 0-1 mm fraction (in percents);
- the degradation index (D) – represents the ratio between the crushing index for the material after ($C_{a.r.}$) and before ($C_{b.r.}$) reduction : D = $C_{a.r.}/ C_{b.r.}$

In Table 1 we present the experiment conditions and the results obtained at the pre-reduction of 10 sorts of iron ores previously agglomerated.

Table 1. Ore reduction experiments

Sampl. no.	Ore characteristics				Experiment conditions			Reduction characteristics		Resistance in hollow roll	
	Fe (%)	FeO (%)	CaO/ SiO_2	Granule Size (mm)	Time (min)	H_2 flow (l H_2/min)	Temp. (^{0} C)	RD (%)	RV (%O /min)	Re duced	Not re-duced
1	51.75	8.4	1.26	5-10	45	0.0690	825	49.42	1.10	61	82
2	4982	8.85	1.41	5-10	45	0.0698	810	63.82	1.42	53	65
3	51.79	13.18	1.20	5-10	45	0.0713	840	43.41	1.96	69	94
4	53.09	7.49	1.32	10-20	45	0.0699	835	57.02	1.28	56	76
5	52.48	12.74	1.23	10-20	45	0.0701	840	45.07	1.00	71	91
6	53.59	10.54	1.71	10-20	45	0.0698	825	64.23	1.43	46	88
7	53.01	10.37	1.02	5-20	45	0.0700	835	39.41	0.83	79	94
8	54.68	8.30	1.12	5-20	45	0.0700	840	42.20	0.94	73	92
9	53.27	7.77	1.30	10-30	45	0.0698	840	59.18	1.32	66	80
10	43.50	8.60	1.80	10-30	45	0.0700	835	62.19	1.38	51	93
11	48.6	10.18	1.20	5-10	46	0.072	870	50.74	1.10	78	88
12	48.7	9.32	1.35	5-10	46	0.067	860	40.20	0.87	76	88
13	51.5	10.00	1.31	5-10	46	0.064	830	50.05	1.09	66	83.8
14	51.98	8.03	1.35	5-10	45	0.070	834	59.40	1.32	79.8	86.2
15	50.47	10.32	1.35	5-10	46	0.072	818	48.82	1.06	68	85.7
16	48.6	10.18	1.20	10-20	46	0.073	855	63.45	1.38	66	90
17	48.7	9.30	1.35	10-20	46	0.068	878	65.32	1.41	68	87
18	51.5	10.00	1.31	10-20	46	0.067	830	54.81	1.19	50	80
19	51.98	8.03	1.35	10-20	45	0.071	838	63.14	1.40	64	75.5
20	50.47	10.32	1.35	10-20	46	0.072	818	48.82	1.06	68	85.7
21	48.6	10.18	1.20	10-20	46	0.072	878	56.1	1.21	70	72
22	48.7	9.32	1.35	10-30	46	0.069	885	52.74	1.15	69	86
23	51.5	10.00	1.31	10-30	46	0.069	825	57.20	1.24	42	59.6
24	51.98	8.03	1.35	10-30	45	0.070	843	57.05	1.27	69	78.7
25	48.6	10.18	1.20	10-30	46	0.072	870	48.74	1.08	73	87
26	48.7	9.32	1.35	unsorted	46	0.072	888	38.74	0.84	71	87
27	51.98	8.03	1.35	unsorted	45	0.071	841	57.53	1.27	69	78
28	50.47	10.32	1.35	unsorted	46	0.069	815	56.14	1.22	44	73.9

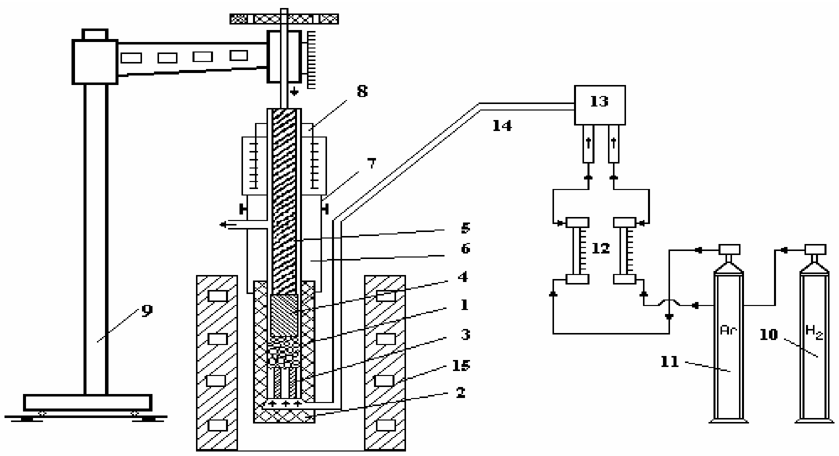

Figure 1. The experiment plant

1- graphite crucible; 2- gas distributor; 3- intermediary plate; 4 – piston; 5 – rod; 6 – graphite support; 7 – seal device; 8 – piston support; 9 – fixed support; 10 – H_2 cylinder; 11 – reducing gas cylinder; 12 – measuring device; 13 – gas mixer; 14 – gas pipe; 15 – induction electric furnace

Analyzing the data from Table 1 we can conclude:

- □ generally, an optimal reduction degree can be obtained from granule size of about 15 – 25 mm;
- □ the easiest reducible materials are the ferrous ones with the basicity.
- □ B = CaO/SiO_2 between 1.35 and 1.7; a medium reducibility is reached by the samples with B = 1.2 – 1.35 and the samples with B ≤ 1.2 being more difficult to reduce;

The tests we made shown that the higher is the reduction degree the higher is the crushing degree. Because pre-reduced materials obtained by reducing the iron ores (crude or prepared) are used in the blast furnace or the electric arc furnace, replacing the iron scrap, it is very important to know the behavior of these materials during the heating – the correlation between the reducing degree and their melting and softening temperatures. That is why we tested the softening of these materials. The plant we used to run these tests is presented in Figure 1.

Table 2. Data on the melting and softening characteristics of the agglomerates used in Romania

Sampl. no.	Chemical composition							Reduction degree (%)	Characteristics temperatures		
	FeO (%)	SiO_2 (%)	CaO (%)	MgO (%)	Al_2O_3 (%)	Fe (%)	B		T_{cz} (^0C)	T_{mch} (^0C)	ΔT (^0C)
1	1.26	1372	25.53	3.28	4.11	39.53	1.86	58.44	1010	1230	220
2	1.53	13.9	24.74	1.86	1.40	42.03	1.78	62.50	765	1240	475
3	3.11	13.75	24.71	1.29	2.16	41.18	1.79	70.00	1080	1320	240
4	6.59	10.28	26.16	3.72	0.28	43.65	2.54	68.00	1010	1330	220
5	8.52	10.60	24.73	3.40	1.76	43.13	2.33	69.80	1000	1330	330
6	7.40	11.05	23.56	5.45	1.96	43.18	2.13	70.35	980	1375	395
7	4.51	12.96	24.63	0.72	1.56	47.49	1.90	69.80	980	1210	230
8	10.56	12.64	24.11	2.80	3.06	44.26	1.90	53.60	1025	1240	215
9	3.64	11.10	24.37	4.74	1.89	44.94	2.10	54.64	1100	1270	170
10	3.94	10.08	24.72	2.49	0.21	44.98	2.45	58.50	1100	1250	150
11	8.60	10.38	20.35	1.57	0.31	46.81	1.95	56.51	1020	1240	220
12	8.20	9.52	17.12	2.75	3.49	48.77	1.79	50.57	1100	1360	260
13	19.90	7.00	14.43	3.00	1.90	51.79	2.06	60.84	1190	1365	175
14	16.24	8.08	16.25	2.15	3.64	52.36	2.01	50.53	1180	1295	115
15	19.93	7.93	16.00	0.87	4.72	49.84	2.01	58.00	960	1090	130
16	25.93	6.43	11.60	2.96	0.86	58.51	1.78	78.80	1170	1380	210
17	8.20	9.52	17.18	2.75	3.49	48.77	1.79	68.92	1155	1330	175
18	8.26	7.70	11.86	2.25	6.62	53.72	1.54	75.77	1160	1420	260

The experiment results are presented in Table 2. The experiments consisted of:

- ❖ from the crushed and screened material, we took a 3-5 mm fraction in samples of 240-310g;
- ❖ we heated the sample with 50-60^0/minute;
- ❖ starting at 750^{0}C we blew argon with 6.5-7.5 l/min., and at 900^{0}C we blew hydrogen with 8 l/min. For 8 minutes, so we could reach reducing degrees of about 50-78%;
- ❖ we measured the temperatures every 3 min. and since the piston moved every 2 minutes;
- ❖ we determined the softening temperature when the piston moved firstly and the melting temperature when the piston movement as half the sample's height.

❖ ECONOMICAL AND TECHNOLOGICAL CONSIDERATIONS ON THE USE OF PRE-REDUCED PRODUCTS IN IRON AND STEEL ELABORATING PROCESS

The pre-reduced materials obtained from solid reduction of iron ores (crude or prepared) can be used as raw material in the blast furnace charge with important economic effects.

Economies that can be obtained by using 1000 kg pre-reduced ore vary between 1 and 34 Euros for a pre-reducing degree of about 70%.

Pre-reducing the materials before using them in the furnace is a method that permits also the amelioration of the structure of the used combustibles (coke, etc.).

The economy obtained at the blast furnace, even in conditions of high energy consumption, covers completely the expenses from the pre-reducing process.

To study the possibilities of using the pre-reduced materials in electric arc furnace as iron sponge with different metallization degrees we made experiments on a 500 kg furnace in which the iron sponge was used 33, 55, and 79,100% of the charge.

We found out that using of iron sponge leads to a reduction of about 20% of the elaborating period and considerable diminish of manufacturing expenses.

❖ CONCLUSIONS

Because they are very important we will mention these conclusions:

- ❖ the agglomerate's granule size doesn't have a notable influence on the "cohesive zone", that's why the recommended granule size (15-20 mm) which can assure a good permeability, can also assure the forming of an appropriate "cohesive zone";
- ❖ the chemical composition of the agglomerate influences the position and especially the width of "cohesive zone".

So, the rise of the MgO contents determines the rise of melting and softening temperatures and a lower position of the "cohesive zone" (i.e. positive influence). Also the rise of the MgO contents determines a higher difference between the melting and softening temperatures and rise the width of the “cohesive zone” (i.e. negative influence).

The necessary value for this parameter can be established following the influence of B on the “cohesive zone” and on charge’s permeability in the granular zone. An optional value for B has to assure a goon mechanical resistance and an appropriate reducibility of the pre-reduced agglomerate.

From the experiments conducted on this last subject we conclude that the optimal value for B is 1.5 – 1.6. This value also assures a favorable influence on the “cohesive zone” that permits us to recommend the use of agglomerate with B = 1.5 – 1.6 in the blast furnace charge.

The laboratory research conducted on a large number of samples leaded us to the conclusion that the reduction degree of the iron oxides has the most important influence on the softening and melting of the agglomerate.

This influence due to the forming in the agglomerate granules of the metallic iron structures that assures a high permeability of the agglomerate layer in plastic state.

We can observe that the melting temperatures rise for a reduction degree over 58%. The same influence but less important manifests on the softening temperature.

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