

Manufacturing and Application of Metalized Ore-Coal Pellets in Synthetic Pig Iron Smelting

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Abstract. The article presents research data on manufacturing and application of metalized ore-coal pellets in synthetic pig iron smelting. A technology of pellets metallization by means of solid-phase reduction of iron from oxides using hematite-magnetite iron ore and low-caking coal as raw materials is described. Industrial testing of replacing 10, 15, and 20% of waste metal by the metalized ore-coal pellets in the coreless induction furnace IST-1 is described. Optimal temperature and time conditions of feeding the metalized pellets into the furnace in smelting pig iron of SCh-40-60 grade are determined.

Introduction

Iron and steel companies suffer from a scarcity of burden materials and thus they have to find new sources of raw materials. Production and application of metallized iron products is a promising solution of this problem [1]. In Russia as well as all over the world direct-reduced iron (DRI) or hot briquetted iron (HBI) produced in shaft furnaces in Midrex® and HYL that uses converted natural gas as a reducing agent [2]. The use of natural gas provides obtaining materials with high percentage of metallic iron (more than 85%) and low percentage of gangue material. But in this process, gas consumption is as high as 300 – 400 m³ per a ton of the metalized material. It hampers adoption of this technology in the regions lacking natural gas [3]. At the same time alternative reducing gases such as hydrogen, coke gas, gases released by coal gasification as well as solid carbon reducing agents are coming into use. Metalized materials reduced by solid agents are produced in revolving furnaces in SL/RN process and in rotary-hearth furnaces in Fastmelt® and ITmk3® processes [4].

Coal and its derivative products are the most common solid reducing agents. There are a number of researches focusing on solid-phase reduction of iron from oxides using coal but a commonly accepted scientifically based technology has not been developed. Experts disagree on their characterization of solid-phase reduction of iron from iron ores oxides using coal because of different physical and chemical properties of coal types and iron-bearing materials, complexity of the system, and simultaneous reduction processes involving solid carbon and gaseous substances. It should be taken into consideration that reactions of direct and indirect (gaseous) reduction of iron from iron ore oxides take place simultaneously.



Based on the research data having been obtained recently we determined conditions for producing metalized materials using coal of different grades as a reducing agent. Our experiments consisted in thermodynamic simulation of solid-phase reduction of iron from iron ore oxides, high-temperature experiments, research into properties of raw and finish materials, as well as mathematical analysis of the obtained data.

This work resulted in a developed technique of producing metalized coal-ore pellets (Figure 1).

In Russia and abroad the metalized raw materials are used for smelting free of non-ferrous impurities steels in arc furnaces [6]. The metalized material can also be used for smelting low-phosphorus and low-sulfur impurity-free non-ferrous metals of synthetic pig iron. Such pig iron is smelted in induction furnaces in on-site foundries at machine-building plants. Cast iron, recycled scrap, and waste metal.

Remelting metalized materials in induction furnaces has a number of evident advantages. In induction remelting the metal in the furnace are constantly mixed in the melting bath. Induction smelting conditions provide degassing of the liquid melt and allow obtaining metal with low nitrogen content because the induction furnace has no high temperature areas unlike which happen under the arcs of the electric arc furnace.

When using metalized materials in burden charge it is necessary to mind their differences from conventional materials. The following characteristics of the metalized materials make them different from waste metal and cast iron: lumps size, apparent density, specific surface, oxide percentage. Table 1 shows characteristics of the metalized pellets, ore, briquettes, and waste metal. It also should be accounted that the metalized materials obtained with coal as a reducing agent contain some amount of solid carbon.

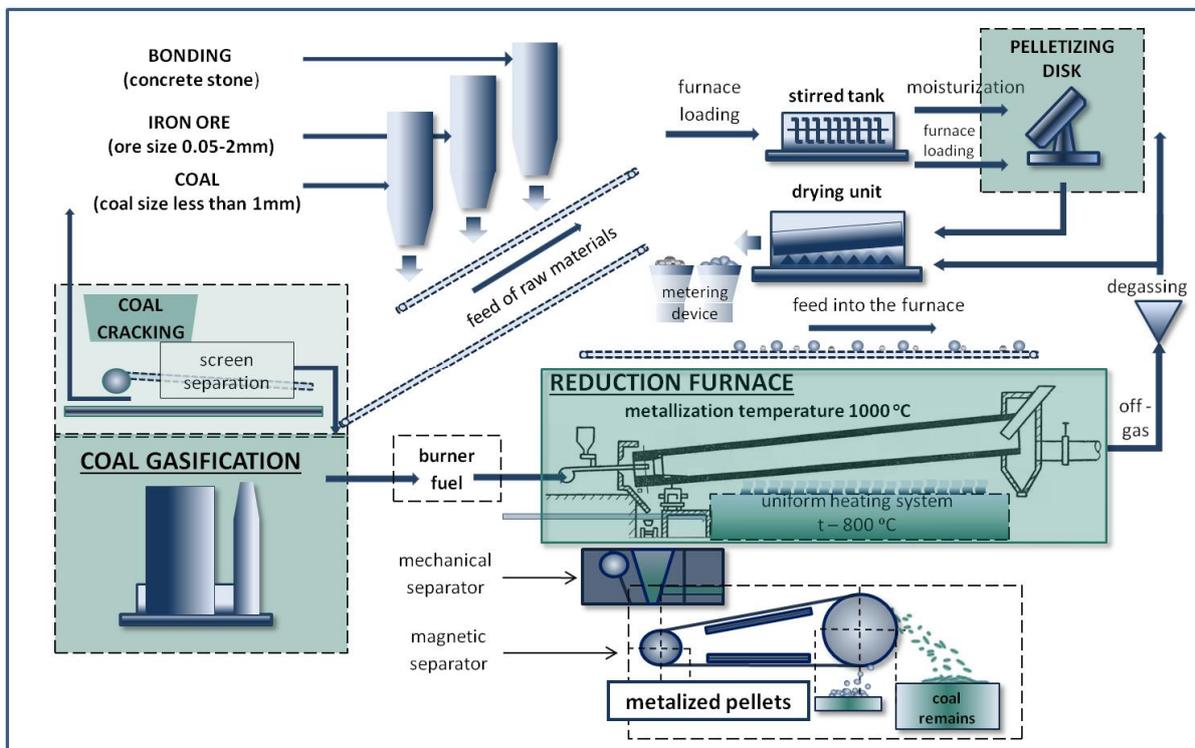


Figure 1. Flow diagram of metalized ore-coal pellets production

Table 1. Physical properties of metalized materials and waste metal

Material	Properties			
	Lump size, mm	Bulk mass, t/m ³	Apparent density, g/cm ³	Total porosity, %
Metalized pellets	3–20	1.6–2.1	2.7–3.3	45–70
Metalized ore	3–20	1.8–2.1	3.5–3.9	45–70
Briquettes:				
– cold briquetting	Up to 70	2.8	4.0	25–30
– hot briquetting		3.2	5.5	15–20
Waste metal	6–2500	0.5–2.9	–	–

Summarizing available data of using metalized materials in induction furnaces we concluded that the metalized materials applied in induction smelting must have the greatest possible percentage of metal and the lowest percentage of gangue materials. To provide conditions for recovery of light metalized furnace-charge by the molten metal it is important to prevent slag cooling. It is also necessary to remove slag from the metal surface. Working with acid slag is possible when acid bottom and lining is used and percentage of phosphorus in the metalized material is low.

Conditions of induction smelting are good for the use of metalized materials containing solid carbon which in its turn can take part in postreduction of iron oxides and act as a carburizing agent. Metalized materials produced using coal as a reducing agent can be efficiently applied as furnace-charge in melting synthetic pig iron.

Thus, development of a technique for using metalized ore-coal pellets in induction smelting is an important task for researchers.

Methods and Materials

To produce a pilot lot of metalized pellets we used iron-ore concentrate (by Abagursk ore-processing plant, city of Novokuznetsk), hematite-magnetite ore (by Tashtagol ore mine), and low-caking coal of CC grade (by Bachatsk coal mine). Table 2 shows properties of the materials in use.

Table 2. Properties of the materials in use

Material	Chemical composition, %							Moisture content W ^r , %
	Fe _{06m}	SiO ₂	Al ₂ O ₃	P ₂ O ₅	S	MgO	CaO	
Iron ore	52.3	14.24	2.51	0.072	0.42	0.76	0.94	5.78
Iron ore concentrate	61.2	6.75	2.2	0.02	0.41	2.31	1.96	8.27
Coal ash	2.6	46.6	16.3	0.37	0.02	1.58	2.5	-
Coal properties	C ^{fix} –70.2 %;		V ^{daf} –20.6 %;		A ^d –6.41 %;			6.7

Table 3 shows the composition of raw ore-coal mixture. Produce 100 kg of metalized pellets took 84 kg of iron-ore concentrate, 28 kg of iron ore, 27.5 kg of CC grade coal, 7 kg of concrete stone.

Table 3. Composition of metalized ore-coal pellets

Material	Chemical composition, %							Moisture content, %	C ^{fix} , %
	Fe _{06m}	SiO ₂	Al ₂ O ₃	P ₂ O ₅	S	MgO	CaO		
Ore-coal pellets	42.36	9.53	2.65	0.03	0.30	1.48	1.35	~10	16.4

The metalizing process was carried out in the batch furnace. Raw pellets together with small-sized coal (0.5 mm) were placed into the furnace. After that the furnace was locked and hermetically sealed with asbestos cord. The small-sized coal was used to maintain the reduction conditions in the furnace.

The furnace was operating as the following: during the first 20 min the temperature did not exceed 200 °C to remove moisture from the materials and prevent pellets cracking; then the temperature was raised up to 1000 °C and isometric soaking was held for 80 min. The resulting pellets were separated from the remains of coal. Table 4 shows average data of chemical analysis of the pellets.

Table 4. Chemical composition of metalized ore-coal pellets

Metalized ore-coal pellets	Chemical composition, %				
	Fe _{met}	Fe _{general}	SiO ₂	CaO	C
	80.20	82.90	11.25	0.30	1.9

Experiment of the technique using metalized ore-coal pellets in the furnace-charge were carried out in coreless induction furnace IST-1. This furnace is applied in a foundry shops of a mechanical plant to produce synthetic pig iron of SCh 40-60 and SCh 44-64 grades.

For experimental smeltings, 10, 15 and 20% of waste metal in the furnace charge were sequentially replaced by metalized ore-coal pellets. The metalized pellets were fed when the melting pot was 60% filled with melted metal which provided the most use of electro-magnetic mixing process in the metal bath. The speed of pellets feed made up 10 kg/min. To each batch of the pellets (10 kg) 0.05 kg of calcium fluoride was added. The pellets having been visually absorbed and the metal surface having been covered with melted slag, the furnace was switched off (Figure 2). After that the metal was tapped into the pouring ladle, metal surface was cleaned from the slag, and the metal from the ladle was poured back into the furnace.

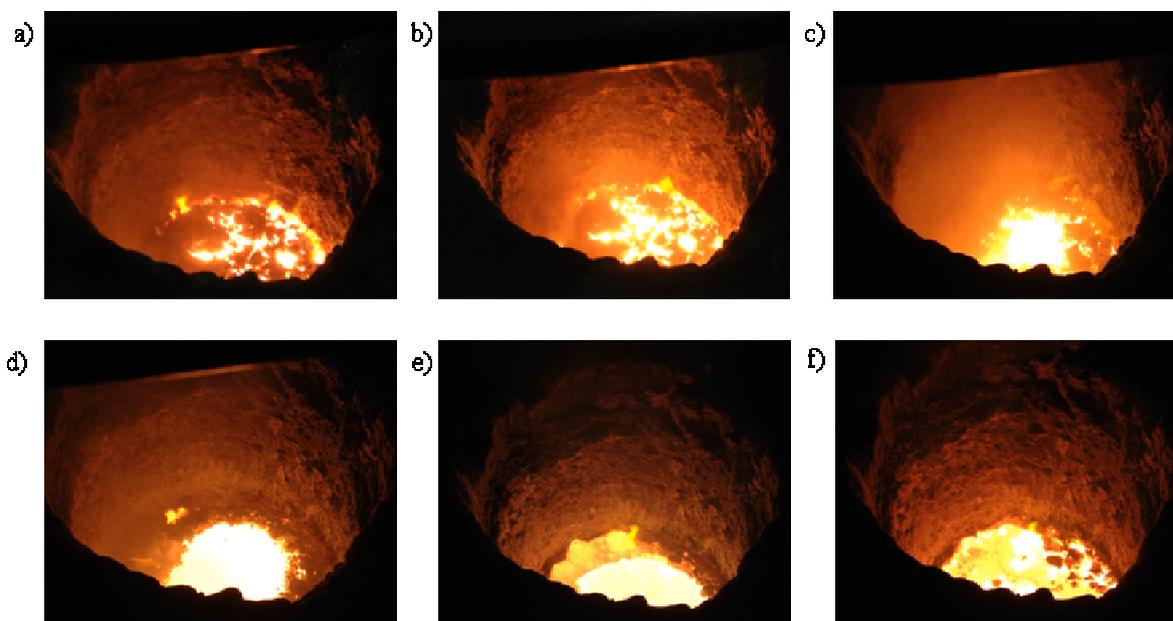


Figure 2. Recovery of 10 kg of metalizes ore-coal pellets during: a – 2 min; b – 2.5 min; c – 3 min; d – 3.5min, e – 4min; f – 5min after feeding into the furnace

Results and Discussion

Characteristics of conventional smelting using metalized ore-coal pellets in the furnace charge are shown in table 5. The smelting mode is shown in Figure 3. Table 6 shows analyses data of metal and slag samples which were collected in experimental smelting.

Table 5. Experimental smelting characteristics

	Conventional smelting	Smelting with metalized pellets		
		10 %	15 %	20 %
Furnace-charge composition, kg/t:				
cast iron	495	495	495	495
metalized pellets	-	115	185	245
recycled scrap	100	100	100	100
waste metal	300	200	150	100
Added materials, kg/t:				
ferrosilicon	4	4.2	4.4	4.5
carbon	5	2.5	2	1.5
Slag quality, kg/t	13	34	72	110
Amount of released gases, kg/t	3	17	21	25
Energy consumption, mJ/t	2124	2358	3437	4100

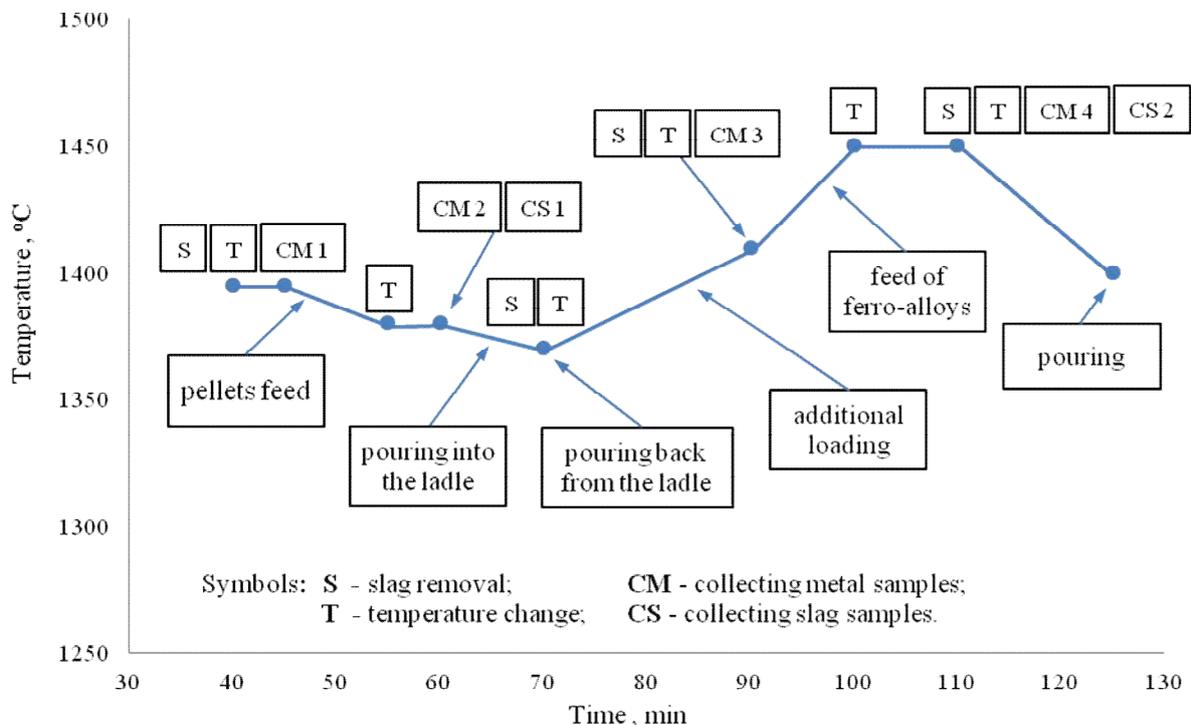


Figure 3. Pig iron smelting using metalized pellets

The experiments show that when batches of pellets are fed into the melting pot filled with melted metal to 60%, the pellets are entrained deep into the melting bath (Figure 3). This phenomenon happens due to the electro-magnetic mixing. Each 100kg of pellets generate 15-20kg of slag. Besides, silicon loss increases since silicon together with carbon evidently takes part in post-reduction of iron oxides found in metalized pellets.

Processes having place during pellets feed can be described as the following (Figure 4). When the pellets are entrained deep into the melting pot and get into the melted metal, a few processes happen simultaneously: post-reduction of FeO accompanied by release of gaseous CO; solving metal phase in the melted metal, carbon recovery and slag formation.

Table 6. Chemical analysis of samples obtained in experimental smelting using 10% of metalized pellets in furnace-charge

Samples*	Weight content, %							
	C	Si	Mn	Cr	Ni	Cu	S	P
Sample 1	3.04	0,91	0.48	0.05	0.04	0.06	0.076	0.10
Sample 2	3.04	0,87	0.49	0.05	0.02	0.05	0.065	0.09
Sample 3	3.08	0,82	0.47	0.04	0.03	0.05	0.068	0.10
Sample 4	2.96	3,03	0.89	0.05	0.03	0.05	0.060	0.10
Slag samples*								
		FeO	SiO ₂	Al ₂ O ₃	CaO	MgO	S	P
Slag sample 1		18.0	58.42	10.13	4.51	-	0.75	0.029
Slag sample 2		3.5	52.79	14.42	6.33	9.39	0.63	0.019

* - conditions of collecting samples are shown in Figure 2.

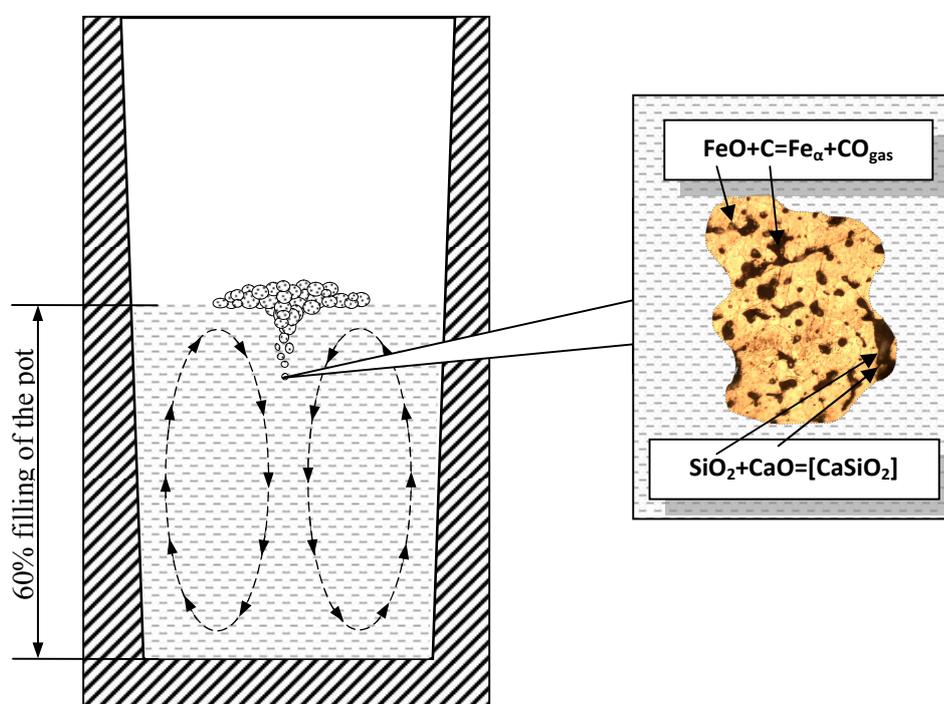


Figure 4. Entraining of pellets deep into the melting pot

The experimental smelting using metalized ore-coal pellets show that the percentage of sulfur in the pig iron does not increase when the quantity of the pellets changes. To minimize a negative effect of slag on the furnace lining it is recommended to implement an intermediate operation: tapping of the slag from the pouring ladle and then loading the metal back into the melting pot.

Conclusion

The resulting data conform to findings of other researches and let us conclude that the metalized ore-coal pellets produced by the developed technology can be applied as furnace-charge in induction smelting of synthetic pig iron. Products cast of the obtained pig iron meet all quality requirements and do not have more defects than cast products made of pig iron smelted with conventional furnace-charge.

Utilization of metalized ore-coal pellets in the furnace-charge provides greater choice of raw materials and technologies for smelting synthetic pig iron in induction furnaces. A continuous process of manufacturing the metalized pellets and feeding them into the furnace at the temperature of 600–800 °C is worth attention. This technique reduces heat consumption and leads to a considerable decrease in capital and operating costs. A preliminary economic estimation of application of metalized materials produced according to the technology developed by the authors showed that if waste metal in the furnace charge is replaced by 15–20% of the metalized ore-coal pellets, the cost of charging materials is reduced by 7%.

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