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PLASMA-INDUCTION TECHNOLOGY FOR REDUCTION PROCESSING OF COPPER CONCENTRATE PELLETS

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ABSTRACT

Industrial remaking of oxide copper concentrates according to classical technologies is economically ineffective because of their limited annual production. This requires the development of a new technology for general remaking of these concentrates, based on plasma - induction reduction melting and casting of copper ingots. The established general technology which is the aim of the present work, includes 3 stages:

- preliminary thermal–mechanical processing of the concentrate, meant to decrease the content of sulfur and iron and to obtain fine dispersed particles suitable for a following pelletization;

- pelletization of the powdered charge;

- plasma–induction reduction melting of pellets and obtaining copper ingots.

The experimental melting was carried out in 50 kg plasma-induction furnace. Following the described technological scheme the obtained extraction degree of copper was 89-93 % at specific consumption of electric power 4,95 kWh/kg liquid metal.

Keywords: *metallurgical plasma technology, plasma torch melting, reduction, plasma-induction furnace.*

INTRODUCTION

One of the directions of the contemporary development of the world metallurgy, that is subordinate to the most modern conception, is characterized by developing of new technologies for remaking the low quality and metal containing waste and raw–materials. Applying classical metallurgical technologies for complex extraction of valuable components from these materials is ineffective [1].

In our country after Waelz process in the production of zinc, 40 000 tons clinker remain per year [5]. This poly-metal waste product contains approximately 150-200 g/t Ag and 2-4 % Cu that are paled up in dumps. Another unemployed raw-material is poor oxide copper ores from which after bacterial leaching and following cementation comparatively rich copper concentrates can be obtained.

The efforts of scholars and technologists for remaking complex oxide copper containing row–materials and waste products are concentrated on creation of new processes and aggregates [2-4].

Metallurgical technologies that use thermal plasma as concentrated heat source and chemically active component, afford wide opportunities for realization of the main idea of the conception for the development of the modern metallurgy.

The application of thermal plasma in metallurgy gives chances for:

- effective remaking of poor natural and waste materials with shortening of the classical extraction metallurgical cycle;
- building economically effective and highly productive installations;
- decrease in specific expense of electric power and labor with good opportunities for utilization of heat;

- creation of non-waste technologies that radically solve contemporary ecological problems [1-3].

In certain cases for implementation of the reduction process together with classical plasma reduction technologies, the plasma induction process could be also appropriate.

The aim of the present research work is to qualify the copper concentrate, obtained by remaking of poor oxide, copper containing row-materials, and to check possibilities for its effective reduction plasma-induction remaking into copper intermediate product, which is appropriate for obtaining copper alloys.

CHARACTERISTICS OF OXIDE COPPER CONCENTRATE

The studied copper concentrate was obtained by bacterial leaching of low-quality oxide copper ores and clinker with sulfuric acid solutions (pH=1,5-2,5) and bacterial mass, and cementation with iron turnings [6, 7]. The concentrate was humid and about 20-25 % of it was in the form of large-scale formation of average size 10-15 mm. Another characteristic feature was the presence of visible amount of non-metal impurities (glass, plastic, paper, etc.) and a considerable quantity unassimilated iron turnings that were highly oxidized. In order to define the main physical properties, the copper concentrate was treated as follows: drying, magnetic separation, grinding, classification (screening) and heat treatment.

After drying at 180^{T}C for 2 hours and humidity below 1 % there were a lot of sintered lumps in the concentrate and its liquidity was very low. The amount of isolated magnetic fraction was approximately 3 %. Analysis showed that as the material was more dispersed the magnetic fraction was isolated more ineffectively. Evidence of this was the comparatively high content of copper (44 %) in it.

The size particles of the concentrate and the possibility for effective decrease of the size of its particles were analyzed. The magnetically separated concentrate (97 %) was grinded in a ball crusher for 15, 30, 45 min., then it was sifted out through 1mm screen. Screen analysis showed that after 15 min grinding 92,9 % of the concentrate was of size under 1,00 mm and was distributed in fractions shown in Table 1.

Table 1. Screen analysis of copper concentrate (fraction -1mm) after different time of grinding.

Concentrate		Sample 1	Sample 2	Sample 3
		15 min	30 min	45 min
№	Fraction	%	%	%
1.	-1,0+0,63	4,4	0,9	0,4
2.	-0,63+0,25	14,3	5,1	4,9
3.	-0,25+0,1	11,6	13,7	13,8
4.	-0,10	69,7	80,3	80,9

This result completely satisfied the requirements for the size of charge particles, their enlargement through pelletization and plasma remaking into dispersed condition.

The obtained results showed that the optimal time for grinding is about 30 min. In conclusion it may be said that through magnetic separation and sifting of the dried concentrate through 1,00 mm screen, impurities unusual for copper concentrate, non-metal admixtures, etc., were removed, as well as a large part of iron turnings that were unassimilated in the cementation. The process of grinding of copper concentrate was necessary only in order to restore its natural fine dispersed state.

The chemical composition of copper concentrate was defined by analysis of 5 samples (1-5, Table 2) taken from different places of 134 kg, dried at 180^{T}C, magnetically separated, grinded and sifted. The content of copper in the concentrate varied between 50-60 %. The copper is in the form of: metal copper (Cu^{o}) 4,01-6,68 %, copper sulphate ($CuSO_4$) 0,30-0,48 %, cuprite (Cu_2O), malachite ($CuCO_3.Cu(OH)_2$), azurite ($2CuCO_3.Cu(OH)_2$) 28,96-31,05 %; chrysocolla ($CuO.SiO_2.2H_2O$) 2,66-3,03 %; chalcosine (Cu_2S), covelline (CuS), bornite (Cu_2FeS_4) 5,10-7,09 %; chalcopyrite ($CuFeS_2$) 0,23-1,11 %.

The chemical analysis confirmed the expected comparatively high content of iron, which should be kept in mind, when conducting reduction melting of the concentrate. The iron is in the form of: metal iron (Fe^{o}) 0,35-2,21 %; bivalent iron (Fe^{2+}) 3,28-5,56 %; trivalent iron (Fe^{3+}) 5,87-9,12 %. The presence of considerable quantity of hydro-oxides, hydrates, carbonates and sulfates explains the big losses (LWH) when heated (14,3 %). The average humidity of the concentrate was 21 %. Characteristic feature were the major differences in the content of copper and iron in the samples (Cu – from 39,76 to 50,09 %; Fe – from 1,18 to 14,72 %). The content of the other components of the concentrate

Table 2. Chemical composition of oxide copper concentrate (fraction -0,10 mm), %).

№	Cu_{total}	Fe_{total}	S_{total}	MnO	Al_2O_3	SiO_2	CaO+ MgO	Na_2O + K_2O	LWH
1.	59,31	7,12	3,09	0,11	6,02	4,11	0,33	0,56	14,12
2.	60,12	6,83	2,23	0,26	5,16	4,27	0,25	0,61	13,79
3.	54,56	8,11	2,98	0,31	4,38	3,52	0,12	0,72	12,23
4.	56,12	9,18	1,48	0,14	6,17	4,16	0,23	0,49	13,58
5.	51,25	8,26	3,45	0,21	4,24	4,42	0,16	0,26	14,36
6.*	54,59	7,09	1,67	0,15	5,71	3,98	0,18	0,38	13,28

**Sample 6 was taken after quartering of the whole amount of concentrate.*

Table 3. Chemical composition of the obtained metal after melting copper concentrate, %.

№	Cu	Fe	Si	S	Degree of Cu extraction, %
1.	99,53	0,18	0,19	0,10	39,1
2.	99,69	0,10	0,14	0,07	34,6
3.	99,37	0,34	0,13	0,16	41,2

(MnO, Al_2O_3, SiO_2, CaO, MgO, Na_2O, K_2O, $S_{total.}$), remained comparatively constant (Table 2).

PRELIMINARY EXPERIMENTS ON INDUCTION MELTING OF COPPER CONCENTRATE

To check the behavior of the initial copper concentrate under heating and melting, experiments in a laboratory induction furnace with graphite crucible were made.

Fig. 1. Viscous, nonhomogeneous slag whit copper drops.

The copper concentrate was heated up to 1550°C and kept within 10 min being stirred. During the heating at temperature intervals 700-1000°C, intensive gas emission was observed which at the beginning was accompanied by a partial emission of fine powder fraction from the crucible. The gas emission was due to the oxidation of the sulfur and the decomposition of hydrates and carbonates from the concentrate. The slag obtained after melting, was very viscous and foams under the action of the emitted gases. After cooling to room temperature, at the bottom of the crucible some copper was collected and the slag visibly contained considerable amount of metal copper in the form of shapeless formations (Fig.1). This fact showed low interfacial tension on the contact area metal copper – slag, and was the main reason that obstructed the coalescence of the drops of liquid copper. The experiment made it clear that at work temperature the slag was heterogeneous, with very high viscosity, which didn't allow the whole amount of metal copper to settle at the bottom of the crucible. The chemical composition of the obtained metal and the extraction degree of copper from the concentrate in three melts are shown in Table 3, and the chemical composition of the slag - in Table 4. It is seen that the obtained metal is comparatively pure, but its extraction degree is very low and the slag contains a lot of copper. More over there is mainly Fe_2O_3, SiO_2, Al_2O_3 in proportion that gives high melting temperature, respectively high viscosity at the temperature of the experiment. The roentgenogram of this slag shows that the relation between the intensity of the lines and the background wasn't significant. The reason is that silicon combines with a number of elements and forms "glasses" – amorphous phases which naturally don't have lines on the roentgenogram, but only raise the background level.

The certain phases in the slag are Al_2O_3 and $CuO.Al_2O_3$ (more exactly the formula is $[Cu, Fe]O.Al_2O_3$). A part (approximately 11,44 %) of the copper in the slag was in the form of metal and the rest (approximately

Table 4. Chemical composition of slag after melting copper concentrate, %.

№	Cu_{total}	$Cu_{con.}$	$Cu_{met.}$	Fe_2O_3	S	MnO	Al_2O_3	SiO_2	CaO + MgO	Na_2O + K_2O
1.	24,25	13,08	11,17	26,88	2,52	0,42	18,97	12,50	2,83	1,55
2.	26,03	13,88	12,15	26,09	2,31	0,41	18,38	11,98	2,71	1,49
3.	23,41	12,40	11,01	27,40	2,43	0,44	19,29	12,71	2,93	1,57

13,12 %) was in bound state. Obviously, for increasing the extraction degree of copper from concentrate, it was necessary to add certain quantity of reducer in the charge. Iron oxides are logically to be reduced and the obtained iron to be dissolved in the copper.

The preliminary experiments made it evident, that for the elaboration of pyrometallurgical technology for remaking of copper concentrate, it was necessary studies in two directions to be made:

- to find an optimal chemical composition of the slag that provides low melting temperature, respectively viscosity and maximal interfacial tension in the contact area with metal copper;
- to choose optimal quantity of reducer for the complete reducing of copper oxides and to restrict the reducing of other oxides present in the concentrate.

OPTIMIZING OF PHYSICOCHEMICAL PROPERTIES OF SLAG AND REDUCTOR

For optimizing the physicochemical properties of the slag and for specifying the optimal quantity of the reducer 3 series experimental melting were made with adding CaO (lime) in quantity 5, 10 and 15 % of the mass of the charge, as well as 10 % CaF_2 (fluorite). Coke was added as a reducer in a quantity that was necessary for 100 % reduction of copper oxides in the concentrate.

The amount of lime was studied in order to achieve minimal viscosity in the system Fe_2O_3-CaO-Al_2O_3-SiO_2 at 1550°C, 5-10 % fluorite had diluting effect on slag with similar composition [8].

The melting was held under time-temperature conditions analogical to those in the first experiments.

Three experiments were carried out each series and the average results from the chemical composition of the obtained metal and slag are represented in Tables 5 and 6.

With the increase of CaO, the melting temperature and the viscosity of the obtained slag decreased. Best results were achieved in experiments whit 15 % lime-high-liquid slag without entrained metal copper. Slag samples whit added slag forming CaO and CaF_2 in phase composition were similar to the first (presence of amorphous phases is also possible). The extraction degree of copper from the concentrate (Table 5) raised from 51,2 % to 98,6 %, which was mainly due to improvement in the physicochemical properties of the slag and the increases of the quantity of the reducer.

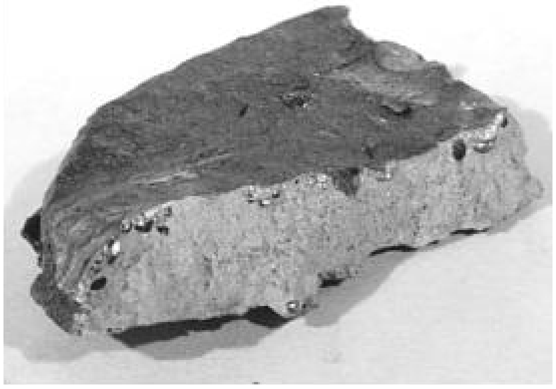

Fig. 2. Copper obtained in case of adding 15 % CaO, 10 % CaF_2 and 100 % reducer

Fig. 3. Slag obtained in case of adding 15 % CaO, 10 % CaF_2 and 100 % reducer.

PLASMA-INDUCTION REDUCTION MELTING OF PALLETIZED COPPER CONCENTRATE

To carry out experiments on pyrometallurgical extraction of copper from carburized copper concentrate through plasma-induction reduction melting, pellets were produced where the raw-material was heated in advance to constant weight at 900°C to remove the basic quantity of sulfur.

The composition of the charge for the production of pellets was: copper concentrate ($Cu_{total.}$ 54,59 %; $Fe_{total.}$ 7,09 %; MnO 0,15 %; $S_{total.}$ 1,67 %; Al_2O_3 5,71 %; SiO_2 3,98 %; CaO+MgO 0,18 % and Na_2O+K_2O 0,38 %) coke 120 %, lime 15 % and fluorite 10 %.

Table 5. Quantity of obtained metal and slag and the extraction degree of copper from the concentrate.

№	Coke, %	Metal, кg	Slag, кg	Cu- Fe Oxide phase, kg	Degree of Cu extraction, %
1.	80	14,1	19,3	11,8	51,2
2.	100	20,2	24,3	0	73,4
3.	120	27,1	17,9	0	98,6

Pelletization of oxidic copper concentrate was carried out in pelletizators with diameter 1200mm, board height 240 mm, angle 52° and experimentally defined technological rotation speed 28 min^{-1}. The amount of the added water was 26 %. The productivity of the process of pelletization was 50 kg/h.

The next technological stage was drying of the produced pellets to isolate the humidity.

Reduction melting was carried out in 50-kg plasma-induction furnace (Fig. 4) [9-11]. This furnace is a combination of classical induction furnace with metallurgical DC arc plasma torch “PLASMALAB,” installed above a water-cooled roof. The plasma torch works under the system of “transferred arc”. For the purpose, a water-cooled bottom electrode-anode was additionally installed at the bottom of the furnace. The induction furnace had 40 kW power, frequency 3,2 kHz and basic line. The plasma torch was electrically supplied by power 150 kVA and worked at maximal electric power 350 A.

The plasma arc was started and small portions of pellets were added. After their melting, pellets were added periodically till the furnace was filled up with metal and slag. Because of the non-conductive charge (pellets) the induction heating was turned off till 1/3 of the volume of the furnace crucible was filled. Within the period, the plasma torch worked at maximal capacity (250 A and 100 V) at length of the arc 100-120 mm. After switching on the induction heating, the power of the plasma torch decreased (150 A and 100 V).

The crucible of the furnace filled up with liquid metal and slag in 45 min, the adding of pellets was ceased and the induction power was restricted to 20 kW. The length of the plasma arc was fixed at around 100 mm and the electricity of the plasma torch decreased to 100 A. The plasma-induction furnace worked under these energy parameters for 15 min. At this time the reduction process ended, the metal and the slag were completely separated and the technological temperature for taping was reached – 1300°C.

After switching off the power supply of the plasma-induction furnace, the metal and slag were tapped together into a heated at 250°C iron mould.

The technological process, form loading the first portion of pellets to pouring out the metal and slag, lasted approximately 60 min. (at heated up furnace). Over this time, approximately 43 kg pellets were remade, from which at the average were obtained 17 kg metal of chemical composition Cu 92-96 %; Fe 3-5 %; S 0,5-1,5 % and main slag of chemical composition CaO 55-62 %; SiO_2 8-12 %; Al_2O_3 12-16 %; Fe_nO_m 7-11 %; Cu_20–traces. The obtained copper alloy contains some iron (3-5 %) and sulfur (0,5-1,5 %), which suggested the additional oxidative processing [12].

The average degree of extraction of copper from concentrate was 92,3 %.

The average specific consumption of electric for

Fig. 4. 50-kg Laboratory Plasma-Induction Furnace “PLASMALAB” [9].

Table 6. Chemical composition of metal and slag, %.

№	Coke, %	Metal			Slag					
		Cu	Fe	S	Cu_2O	Fe_nO_m	CaO	$S_{total.}$	Al_2O_3	SiO_2
1.	80	99,81	0,03	0,16	28,63	12,43	40,16	0,62	11,63	6,32
2.	100	98,34	1,31	0,35	23,21	11,31	42,64	0,45	12,84	8,61
3.	120	93,20	5,56	1,24	0	8,46	59,83	3,67	14,91	10,16

the whole quantity of remade pellets was 4,95 kWh/kg produced metal. It should be kept in mind that the increase of the power and the capacity of the plasma-induction furnace leaded to decrease of the specific consumption of electric power [11]. This was mainly due to the fact that with the increase of capacity of the furnace the heat losses decreased.

CONCLUSIONS

The conducted experiments on plasma-induction reduction extraction of copper from the cementation copper concentrate made it possible the following main conclusions to be made:

For the complete extraction of the copper from the concentrate, it was necessary to form base slag through adding lime and fluorite ;

The optimal amount of the reducing agent was 120 % of the stoichiometric quantity needed for the complete reduction of the copper oxides present in the charge;

In the obtained copper alloy inevitably existed some iron (3-5 %) and some sulfur (0,5-1,5 %), which suggested the additional oxidative processing.

92,3 % average extraction degree of the copper from the concentrate was achieved, at specific consumption of electric power 4,95 kWh/kg produced metal;

The copper alloy, obtained as a result of the developed technology is a suitable intermediate product for the production of different brands aluminum bronzes, containing 2-4 % iron;

In industrial application of the process it will be better to use a chanal plasma-induction furnace, working at mains frequency that is specially constructed for the purposes of the suggested technology;

The tapping of the produced metal and slag must be held through siphon slag separator (in case of bending furnace), or through separate tap-holes, situated on different levels along the height of the furnace (in case of stationary furnace).

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