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Electrohydraulic ragging of metallurgical silicon

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The article presents a crushing technology of metallurgical silicon. The proposed ore crushing method is based on the use of the energy of an impulse shock wave resulting from an electrical spark discharge in a liquid. Electro-hydraulic technology is one of the most acceptable in production environment because it provides intensive ragging and crushing of the test material.

Keywords: Metallurgical silicon, Electric hydropulse method, Discharge energy, Interelectrode gap at a commutation switch

INTRODUCTION

Currently, on account of the high content of metal impurities in metallurgical silicon it is not used to produce photo cells, since the purity of the silicon should be at least 99.99% [1, 2]. Material of this purity is currently supplied to the world market by about 10 companies (from USA, Japan, Germany and Italy), and the number of manufacturers does not actually increase. This is due primarily to the fact that metallurgical silicon refinement technology is very complex and expensive, so the required manufacturing investments exceed several billion dollars [2].

Electrical properties of silicon crystals substantially depend on the amount of impurities. Besides, ferrous metals including iron, chromium, manganese, heavy non-ferrous metals such as copper, nickel and alkali metals such as sodium and potassium are unnecessary impurities; so to produce photoelectric current converters it is necessary to reduce the number and contents of the elements [3].

However, metallurgical silicon containing more than 98.8% of silicon in the form of powder having a particle size greater than $6 \cdot 10^{-7}$ m is used in manufacturing organic silicon compounds and trichlorosilane as a source raw material to produce semiconductor silicon [3].

In connection with the above, the objective of this work is to break up metallurgical silicon by electro-hydraulic pulsed discharge, and to match the basic electrical and energy parameters of an electric hydropulse plant [4].

Materials and routine of the experiment

To investigate breaking and ragging of metallurgic silicon, an electric hydropulse plant with a crushing unit was developed and assembled in the Laboratory of electrohydrodynamics at the E.A. Buketov Karaganda State University [5].

In the crushing unit there is a cylindrical chamber where a linear system of electrodes is installed. The positive electrode is set vertically, while the negative electrode is the bottom of a hemispherical metal chamber. When a high power pulse passes through a liquid medium, which is a wet mass, an electrical breakdown occurs there, accompanied by a hydraulic shock of high destructive power.

The aqueous medium, in which the high-voltage electric discharge occurs, is a transformer of the energy released in the discharge channel, and due to low compressibility it leads to a sharp increase in pressure.

Due to electrohydropulse effect, a hydrodynamic fluid flow and an acoustic wave arise in the processed medium; and cavitation results from local pressure reduction in the fluid. At the same time a cavitation bubble, entrained by the fluid flow to a greater pressure area, collapses and causes a shock wave. After the bubble collapse, microshocks of cumulative jets are formed. The mixture, accelerated by the discharge channel broadening at a high rate, moves away in all directions.

At the start of the process, the discharge channel dilates at a maximum rate; on completion of the current flow due to the inertia of the medium, the space of the discharge channel continues to extend, it reaches the maximum size and then falls into contraction. When the space extends, the

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temperature and pressure in the discharge channel fall, and at its contraction they rise, i.e. damped pulsation of the space occurs.

When solid substances are exposed to electrohydraulic action in aqueous solution, the intensity of the crushing process grows by the impact of the additional pressure due to cavitation. Indeed, at each solid particle a cavitation microcavity occurs; when collapsing, the latter increases its mechanical action [4-7].

During testing, the initial diameter of the metallurgical silicon particles averaged $3 \cdot 10^{-3} \div 15 \cdot 10^{-3}\, ì$.

Tests at the electrohydraulic plant were carried out at various values of discharge energy $(W = 65 \div 245\ Äæ)$, capacitor bank capacity $\left(\tilde{N} =: 0{,}25; 0{,}4; 0{,}8; 1 \cdot 10^{-6} F\right)$, interelectrode gap at a commutation switch $\left(l_p =: 6; 8; 10; 12 \cdot 10\, ìì\right)$ and a pulse repetition rate of 5 to 15 Hz. The value of the applied voltage to the switching device was adjusted from $15 \cdot 10^3$ to $40 \cdot 10^3\, \hat{A}$.

RESULTS AND DISCUSSION

During the experiment, the best value of the interelectrode gap at the commutation switch was 10 mm and the diameter of the fractions undergoing the most intense breakup was $d_{ôð} = 7 \cdot 10^{-3}\, ì$. The fineness number increases with increase in the specific energy supplied to the discharge channel. This can be explained by the fact that on the shockwave way a microcrack network is first formed in the substance structure and it causes a complete stress state. The results of the laboratory tests carried out at different values of capacitance of the capacitor bank are shown in Figure 1.

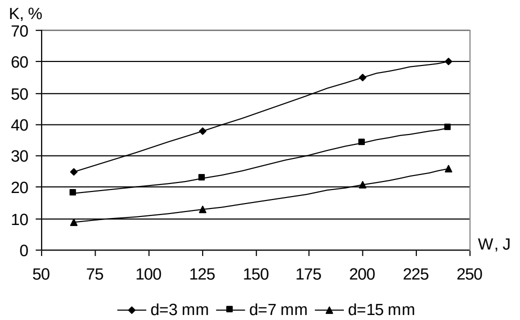

Fig. 1. Dependence of silicon fineness number on the discharge energy at the commutation switch

As the figure shows, the fineness number of metallurgical silicon crushed to 0.5 mm is rather low at the discharge energy value of 65 J, and when the discharge energy increases from 125 J to 250 J the fineness number of the material increases at about the same rate. By the impact of a series of pulses of $10^{-5} \div 10^{-4}\, ñ$ width on solid fractions, they initially cumulate plastic strain, which on the one hand increases its strength to some extent, but in the defect structure areas voltage arises which destroys materials.

The analysis of the qualitative and quantitative elemental composition of materials before and after processing at the electropulse plant was performed on a scanning electron microscope Philips SEM 515 in accordance with the standard technique of "The testing procedure of the structure of a solid body surface using scanning electron microscopy," at the Tomsk State University. The chemical analysis and elemental composition of the metallurgical silicon processed at the electropulse plant were compared with the samples crushed by a gyratory mill. The analysis of the element composition after mechanical operation and electric pulse machining shows different changes in the processed samples (Table 1).

Table 1. Elemental composition of metallurgical silicon

Element	Cone mill	Electropulse installation
Silicon (%)	99.78	99.96
Aluminum (ppm)	79	55
Sulfur (ppm)	74	12
Magnesium (ppm)	152	53
Potassium (ppm)	18	-5
Vanadium (ppm)	14	-8
Phosphorus (ppm)	19	29
Calcium (ppm)	301	76
Iron (ppm)	1264	507
Nickel (ppm)	40	12
Chromium (ppm)	83	16
Copper (ppm)	428	23
Titanium (ppm)	56	19
Boron (ppm)	463	142
Sodium (ppm)	57	0

After the electro-hydraulic processing, the content of ferrous metals decreased: iron from 1264 ppm to 507 ppm, chromium from 83 ppm to 16 ppm. The content of heavy non-ferrous metals decreased too. Particularly the copper content decreased from 428 ppm to 23 ppm, the content of nickel from 40 ppm to 12 ppm, and of alkali metals the content of sodium fell from 57 ppm to 0 ppm, and the potassium content from 18 ppm to -5 ppm. Reduction in inclusions may be due to the fact that during the treatment process taking place in a liquid medium, silicon lumps are cleaned by pulses.

CONCLUSION

This is the first experimental study of the effect of underwater electrical explosion on the selectivity of ragging and crushing of metallurgical silicon. In accordance with the fineness number of the material under examination, the best optimal parameter for the discharge energy is 200 J. By the electro-hydraulic technology metallurgical silicon is crushed to fractions of preset parameters.

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