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Study of the Physical-mineralogical Properties of Quickly-chilled Slag and Possible Methods of its Further Processing

SamadovAlisher, AskarovaNilufar, KholiqulovDoniyor

Director of the Almalyk branch of the Tashkent State Technical University, doctor of technical sciences, Almalyk, Uzbekistan;
Head of Department of Metallurgy, Tashkent state technical university Almalyk branch, Almalyk,Uzbekistan;
Deputy Director for Research and Innovation Almalyk branch of the Tashkent state technical university, PhD, associate professor, Almalyk, Uzbekistan

ABSTRACT: The physico-mineralogical properties of fast-cooled slags were studied. The possibility of further processing of fast-cooled slags by flotation was studied.

KEY WORDS: Slag, Rapid Cooling, Mineral, Grinding, Flotation.

I.INTRODUCTION

Despite the wealth of natural mineral resources of Uzbekistan, the effective planning of economic development is impossible without taking into account the possibility of engaging in the processing of industrial waste, in which the content of valuable components is often much higher than in the primary raw materials produced.
In the area of the slag heaps, the chemical composition of the soil is altered, readily soluble compounds are washed out, groundwater is polluted and thus irreparable harm is caused to nature.

Metallurgical slags should be considered not only as a source of additional production of non-ferrous metals, but also as a very valuable raw material for other types of industry. Non-ferrous metals, which are of great value for the national economy, should be sought to be extracted by cheap, easy-to-use and effective means. Depleted slag, if it is economically feasible, can be used as feedstock for the production of iron and steel, cement, insulating materials, stone casting, and in some cases, slag can be used as fertilizer.

About 400 thousand tons of slag dumps with an iron content up to 30-35 %, copper up to 1,5 %, gold 0,2-0,4 g/t goes to the slag heap of JSC Almalyk Mining and Metallurgical Combine (JSC «Almalyk MMC») annually from the copper smelter. Slag dumps are a source of environmental pollution. At the same time, they can be considered as a technogenic iron ore deposit containing non-ferrous and noble metals.

II. SIGNIFICANCE OF THE SYSTEM

The focus of the article is on the object of study - the slag of copper production of JSC «Almalyk MMC» of a copper smelter and a possible method for its processing.

One of the most difficult problems in the processing of slags is grinding, which is associated with high material and energy costs. Currently, JSC «Almalyk MMC» slag copper production is processed together with the ore by flotation. According to this technological scheme, the slag is crushed in one of the mills at the grinding redistribution stage up to -0,074 mm and after mixing with the crushed ore enters the flotation. However, the high hardness and abrasiveness of the slag does not allow to increase the extraction of copper containing in the slag. The copper content in the concentrate does not exceed above 12 %. To open copper minerals in the slag, grinding of minus -0,044 mm is required, which requires additional consumption of reagents and electricity during grinding (consumption of armor and grinding media) and flotation. Thus, there is an extremely limited possibility of slag processing by the flotation method compared with the required amount of its processing.

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The authors of the work carried out research on the study of the physico-mineralogical properties of rapidly cooled slag, which is necessary for choosing the direction of further technological research for processing.

THE DEVELOPED TECHNOLOGY ALLOWS:

- slag processing using the method of rapid cooling;
- the use of rapid cooling allows the sulfide suspension to form in the slag, and changes to the structural properties of the slag, which helps to improve the grindability and floatability of the copper minerals;
- combined enrichment allows you to comprehensively extract the valuable components that are present in the composition of the slag, to separate non-ferrous and precious metals.

The scientific and technical solution of this problem is the improvement of the leading technology for the extraction of valuable components from the slag of copper production.

III. LITERATURE SURVEY

To date, there is no consensus on technology for extracting copper from copper slag. Slag processing by flotation is most developed in Japan and Finland [1]. In the CIS countries, the processing of copper slag is practiced in Kazakhstan, Russia and Uzbekistan. Currently, a large variety of copper slag processing methods is being studied [2]: hydrometallurgical, biochemical, depletion using chlorinating agents, depletion using direct current, pyrometallurgical-flotation and others. But in industrial practice, only two methods of slag processing are widely used: reduction-sulphiding depletion in electric furnaces and the flotation method.

At the Harjavalta plant, suspended smelting slag and converter slag are separately crushed to a particle size of 4 mm. The copper content in the slag suspended smelting 1-1,5 %, in the converter slag 3-6 %. After averaging at a copper content of up to 3 %, the slag is crushed in two stages to the final ton of milling of the 90 % fraction – 0,053 mm. Flotation is carried out in two stages with the return of sand to grinding. The tails of the main flotation is subjected to control flotation. As a result, copper concentrate is produced with a copper content of ~ 20 % with copper recovery of ~ 90 %. The copper content in the flotation tailings is 0,1-0,2 % [3, 4].

It should be noted that good slag flotation rates are achieved only with their slow cooling. This is due to the fact that in slowly cooled slags, sulfide particles have a particle size of 0,015–0,04 mm, in normal, and rapidly cooled slags, the particle size of sulfide particles is much smaller. However, slowly cooled slags are more abrasive and hard. Since slag flotation at foreign plants is carried out in separate workshops, this allows the use of higher quality construction materials for grinding equipment in small volumes. At the enterprises of the CIS, where the flotation of slags is carried out jointly with the ore, difficulties arise with the grinding of slags and equipment wear, so slow cooling is not used. To obtain high flotation rates, it is necessary to process slowly cooled slags in a separate grinding and flotation cycle [4].

In foreign plants, slowly cooled slag is subjected to flotation in all cases. The flotation of copper slags is carried out at the plants of Mount Morgan, Tennant Creek (Australia), Samsun (Turkey), Khetri (India), Gorn (Canada), Garfield (USA), etc. In addition, in Finland, Outotec® put into production a model slag processing factory [5].

The process is based on slow cooling of the molten slag, after which the cooled slag is crushed, passes through a wet grinding stage and copper is recovered in the form of a concentrate by flotation. Slow cooling of the slag contributes to the crystallization of copper and copper sulphides, with the formation of separate, large crystals and this is a prerequisite for their separation from waste rock in the following grinding and flotation processes. The process is based on slow cooling of the molten slag, after which the cooled slag is crushed, passes through a wet grinding stage and copper is recovered in the form of a concentrate by flotation. Slow cooling of the slag contributes to the crystallization of copper and copper sulphides, with the formation of separate, large crystals and this is a prerequisite for their separation from waste rock in the following grinding and flotation processes.

Analysis of the reviewed literature and practice of existing enterprises on the problem of the grindability of copper production slags makes it possible to conduct research in the following direction:

- the study of the physical and mineralogical properties of fast-cooled slag;
- comparison of technological parameters obtained during the experiments;
- the choice of the optimal duration of the grinding of fast-cooled slag.

Along with this, it is necessary to study and select the technology for the extraction of metals from fast-cooled slag

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IV. METHODOLOGY

To improve the grindability of slags without deteriorating the floatability of the slags are subjected to two-stage cooling. In the first stage, in the high temperature and liquid or semi-liquid state of slags, they are slowly cooled, at which large sulfide particles are formed, and after this process is over, the slag undergoes rapid cooling, at which thermal stresses are formed and preserved in the solid structure, which lead to growth of grindability, and sometimes self-crushability of slags. For the first time, a method for rapid cooling of liquid slags was proposed on the basis of theoretical analysis: obtaining a sulphide mixture acceptable for flotation of the structure and obtaining easily comminuted hardened slags. When cooling slags, the rate of diffusion of sulfides decreases, which leads to the formation of sulfide particles of small size.

Useful components in the slags of copper-smelting production are copper sulfides, the main of which is chalcocite Cu_2S. In addition, bornite, chalcopyrite, and covelin are found in the slags.
The chemical composition of the slag is given in table 1.

Table 1. The chemical composition of the slag

№	Slag type	Chemical composition,, %									
		Cu	Fe (general)	SiO_2	AI_2O_3	CdO	Zn	Pb	Fe_3O_4	S	MgO
1	Oxygen-flare melting	0,83	31,2	32,6	5,7	0,5	1,2	0,3	17,1	1,9	-
2	Reflective melting	0,39	42,5	30,6	2,2	2,8	-	-	-	0,7	1,9

According to chemical analysis, it is clear that the slag after the conversion of CFP contains 0,83 % of copper, which is considered to be rich in metal ore. This slag requires processing with the extraction of copper and other valuable components.
To study the forms of finding copper and its minerals in “ore” slags, devices Superprob JXA-8800K and Jeol ISM-5910LV were used (Figure 1-2).
For rapid cooling, OFM slags (Oxygen-flare melting) were selected, ordinary water was used for hardening. (or wastewater enterprises) in the ratio of 1 kg of slag 3-5 liters. water. Samples were taken in different cooling modes. Sample No. 1 was taken 20 minutes after pouring, No. 2 after 40 minutes, No. 3 after 60 minutes.

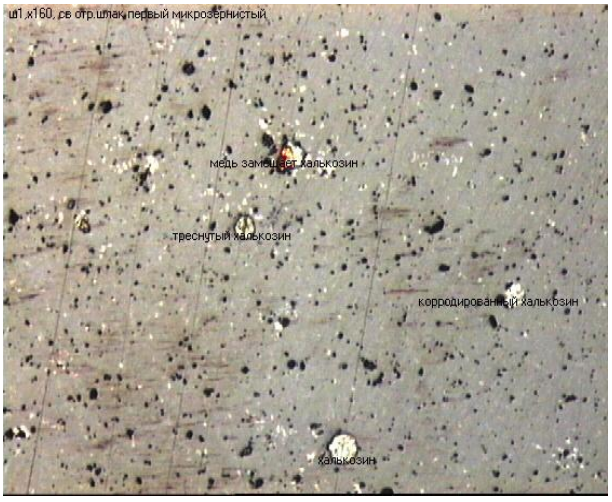

Figure 1. Slag first microgranular
1-copper replaces chalcocite; 2-cracked chalcocite;3-corroded chalcocite;4-chalcocite.

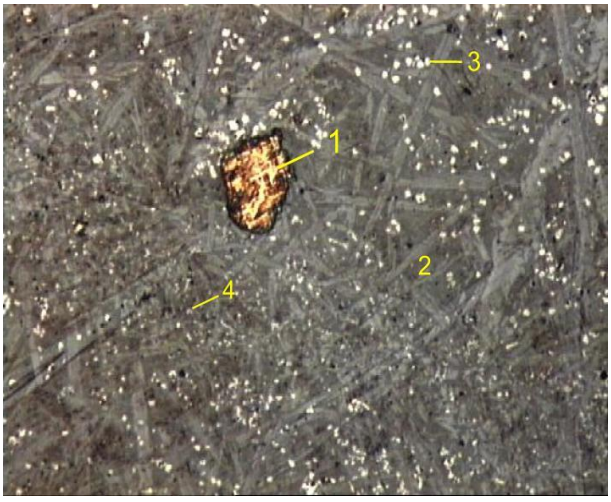

Figure:2. Slag OFM:
1-chalcopyrite; 2-fayalit; 3-magnetite in the form of denrites; 4-copper particles.

Figure -1 shows the primary formation of rather large particles of chalcocite.
Figure -2 shows the already fully formed large particle of chalcopyrite.

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As mentioned in the literature [1], copper and copper sulphide minerals in the slag are opened only when grinding is -0.044 mm. However, for dump slags of natural cooling, such grinding is considered difficult to achieve, since slags are considered abrasive and hard. Fast-cooled slag is easily crushed, and also opening of minerals is achieved by grinding -0.074 mm, due to the rapid cooling, the slag becomes brittle.
Comparative tests were conducted on the grindability of natural and rapid cooling slags, which is given in Table 2.

Table 2. Duration of grinding to class-0,074mm, minutes

Sample number	Grinding time, min. class -0,0074 mm			
	10	20	40	60
1	75 %	-	-	-
2	60 %	77 %	90 %	90 %
3	42 %	57 %	72 %	85 %
4	40 %	55 %	62 %	70 %

Slag sample 1 is considered more fragile, it is crushed to a particle size of -0,074 mm already with a duration of 10 minutes, but in this sample the copper minerals do not have time to be formulated and the extraction of copper is low. Sample 2 achieves grinding of 90 % of the class of -0,074 mm at τ=40 minutes, while settling, the slag already has time to formulate copper minerals of a larger size and extraction can give significant results. Further sedimentation of sample 3 is close to natural cooling, so grinding takes a long time, significant results can be achieved only with τ=60, 85 % grinding. Sample -4 naturally cooled slag is abrasive, solid, requires additional consumption of grinding media and leads to high consumption of energy costs.
Comparative indicators of dry grinding of naturally cooled and fast-cooled slag are shown in Figure 3.

The authors also conducted experiments on the depletion of fast-cooled slag (sample -2) by the flotation method.
Xanthate, T-80 and T-92 were tested as collector reagents for flotation of copper sulfide.
As a result of laboratory studies, it was found that a small amount of grinding time is spent on quickly cooled slag, as well as copper recovery increases to 70 %. The experiments were carried out by grinding 90 % of the class - 0.074 mm. The research results are summarized in table 3.
The results obtained contribute to the fact that the grinding of slags is improved during rapid cooling with a duration of 10-40 minutes. For flotation beneficiation methods, rapid cooling after 60 minutes of sedimentation is optimal, in which copper recovery is 69,3 %

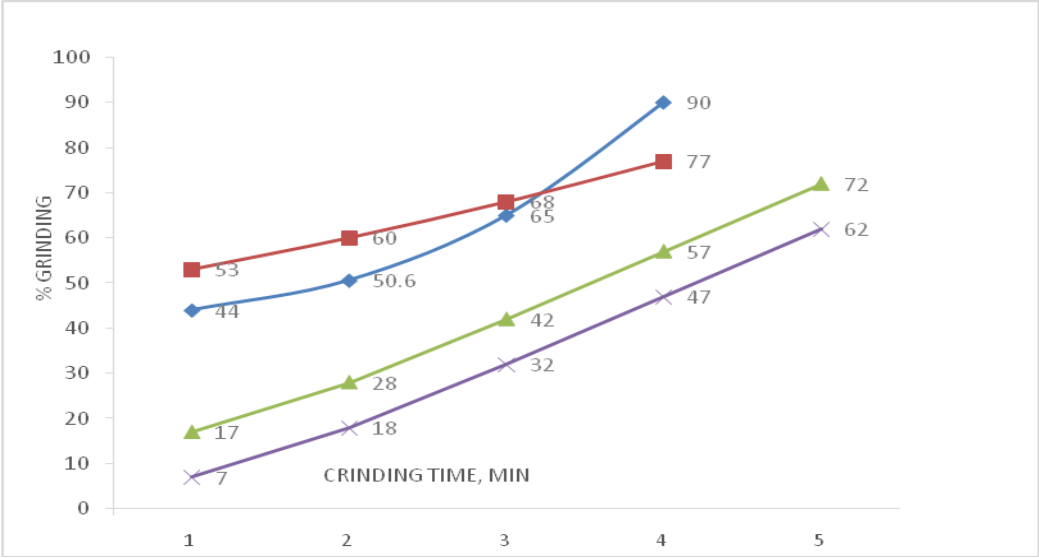

Figure 3.Comparative indicators of dry grinding of naturally cooled and fast-cooled slag.
——— - after 20 minutes unholding; ——— - after 40 minutes unholding;
——— - after 60 minutes unholding; ——— - natural cooling

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Table 3. The results of the flotation of fast-cooled slags

Sample number	Products	Timecooling, min	Exit, %	Copper content, %	Extract, %
1	Concentrate II.	20	4,28	8,6	43,3
	tails		95,72	0,503	56,7
	Total: ore		100,0	0,85	100,0
2	Conc.II cleaning	30	4,016	10,6	50,08
	tails		95,984	0,44	49,92
	Всего: руда		100,0	0,85	100,0
3	Conc.II cleaning	40	4,17	12,5	61,3
	tails		95,83	0,343	38,7
	Total: ore		100,0	0,85	100,0
4	Conc.II cleaning	60	4,18	14,1	69,3
	tails		95,82	0,27	30,7
	Total: ore		100,0	0,85	100,0

VI. CONCLUSION AND FUTURE WORK

• Chemical, mineralogical composition of copper production slag was determined;
• thegrindability of fast-cooled slag was studied for further processing by flotation;
• the floatability of rapidly cooled slag was investigated.

After rapid cooling, the structure of the slag changes, the grindability is improved, and when grinding the grade of -0.074 mm, copper minerals are easily opened, which are easily floated.

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AUTHOR'SBIOGRAPHY

№	Full name place of work, position, academic degree and rank	Photo
1	**Samadov Alisher Usmonovich**, Director of the Almalyk branch of the Tashkent State Technical University, doctor of technical sciences	
2	**Askarova Nilufar**, senior teacher Department of Metallurgy, Tashkent state technical university Almalyk branch	
3	**Kholiqulov Doniyor Bakhtiyorovich**, Deputy Director for Research and Innovation Almalyk branch of the Tashkent state technical university, PhD, associate professor.