Recovery of valuable elements from tailings of the Kachkanar Ore Mining and Processing Plant

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Abstract

We present experimental results on the recovery of valuable elements from wet magnetic separation tailings of EVRAZ KGOK. The plant annually generates 45 million tons of tailings. The problem of the generation of substantial amount of mining waste can be solved through tailings recycling. Of prime importance for the plant is utilization of multi-tonnage technologies of tailings recycling. Ore concentrate was obtained from the tailings by gravity separation (up to 4.5-7.5%). Titanium magnetite from concentrate is easily separated by magnetic separation and can be added to the main product of the plant. The recovery of scandium from pyroxenes is of high potential. Light silicate products of gravity separation are suitable as raw materials for the production of stone fiber. Experiments revealed a less pronounced effect of unwanted melt crystallization during cooling, which creates heterogeneities in stone fiber.

Keywords: tailings, recycling, ore concentrate, stone casting, basalt fiber, scandium

Introduction

The Kachkanar Ore Mining and Processing Plant is part of the EVRAZ industrial holding.In terms of its annual output, the plant is one of the top five largest ore mining enterprises in Russia. EVRAZ is located in the Sverdlovsk region and develops the Gusevogorskoe vanadium-titanium magnetite iron ore deposit. Because of its high content, vanadium is used as an alloy component for high-strength steel grades. The Kachkanar ore bodies associated with the ore massif of the same name are the only source of vanadium-bearing ores in Russia. The plant has been operated since 1956.

The plant's annual output is approximately 55 million tons of iron ore. EVRAZ KGOK currently produces iron ore from three open pit mines, which are further processed in crushing, enrichment, sintering and pelletizing workshops. Tailings produced from wet magnetic separation in the volume of about 45 million tons per year are discharged to the tailings disposal site. Tailings slurries at about 10% solids are dumped at the tailings site, which currently stores 1.6 billion tons of tailings. The company is implementing a project to build a new tailing disposal site using advanced technology of tailings thickening, allowing the tailings to achieve solids concentrations of 65–70%, thus substantially reducing the area of tailings dump as well as the negative effect on rivers (Kuznetsov et al., 2013).

The problem related to the generation of substantial amount of mining waste can be solved through the use of waste processing technologies. The tailing dump can be considered as a technogenic mineral deposit. We studied the possibility of using tailings from the wet magnetic separation. Using individual samples, we analyzed the mineral and chemical composition of tailings.Artificial stone production can be regarded as a promising way of usinga large-tonnage tailings waste. Basalt fibers have recently come into the spotlight (Pisciotta et al., 2015) due to their superior physical and chemical properties, which rank above traditional glass fibers (Chen et al., 2016), which allow one to manufacture a wide range of different materials for construction and technical purposes (Reiterman et al., 2015).

Methods

In this study, we collected 76 kg of tailings from the EVRAZ KGOK tailing dump. Studies were performed at the Faculty of Mineralogy and Petrography of the Perm

State National Research University using a number of integrated methods. These included determination of mineralogy by optical microscopy and X-ray diffraction. The analysis was performed on a Bruker's 2D PHASER powder diffractometer using a copper anode, step time of 0.1 s over an angular range of 5 to 75°2θ from, the duration of one analysis was 15 minutes. The content of minerals was quantified using the TOPAS software. The chemical composition of the tailings was determined by X-ray fluorescence on aBruker's S8 Tiger spectrometer using the Silicates software. The melting of the samples was simulated using a NETZSCH STA 409 PC Luxx synchronous thermal analyzer. The samples were heated to 1430 °C at a step of 10°C/min and then cooled. The chemical composition of minerals from tailings was analyzed using an OXFORD INSTRUMENTS INCA ENERGY 350 spectrometer Analytical conditions were 20 kV accelerating voltage, 10 mA beam current, and a 9 mm working distance.

Results

The particle size analysis of the tailings revealed the presence of a noticeable amount (more than 20%) of gravel-sized grains represented by rock intergrowths and fragments.In order to reliably determine the mineral composition of the tailings and in order to maximize the opening of the intergrowths and the recovery of useful components (titanomagnetite) as free particles, they were crushed to <0.2 mmparticle size.

Optical mineralogical analysis showed that the crushed tailings are mostly diopside (42–74%), plagioclases (7–25%), epidote group minerals (5–15%), amphibolesas hornblende and actinolite (2–15%), titanomagnetite (1–2%), olivine (1%), etc. Chlorites, sulfides, garnets, apatite, ilmenite, few biotite, and spinel are present as a few fractions of percent. The XRD data on individual samples substantially differ from those obtained by optical microscopy because of the presence of abundant intergrowths (e.g., pyroxenes and epidote with plagioclases and amphiboles) and mineral microinclusions. XRD analysis is capable of accurate quantification of the weight fraction of each mineral species and is designed for the accurate identification of intergrowths and microinclusions.

The chemical composition of the crushed tailings is heterogeneous from sample to sample despite the noticeable difference in their mineralogy. This is caused by similarities in the chemical composition of silicate minerals, which dominate in the crushed products (pyroxenes, amphiboles, epidote, plagioclases). The predominant components in the crushed tailings (wt.%) aresilica (44.41–45.31), calcium oxides (20.12–22.51), magnesium (13.32–14.16), iron (9 , 49–10.40), and alumina (6.29–7.94), which account for more than 95% of the mineral mass.

X-ray fluorescence analysis data show that the chemical composition of tailings depends on the presence of the predominant minerals. In particular, the presence of silica and calcium and magnesium oxides is explained by the presence of the mineral species (diopside $CaMg[Si_2O_6]$) having the corresponding composition among pyroxene grains. Alumina is mainly present in plagioclase and epidote group minerals. Iron is found in epidote, amphibole, goethite, and pyrite. The most characteristic feature is the presence of trace elements, such as vanadium (in titanomagnetite) and scandium (in pyroxene). The presence of sulfur is associated with the presence of sulfides, which are also the main concentrators of non-ferrous metals (copper, arsenic, antimony, lead, zinc). Chromium is mainly present in chromiumspinels.

The acidity index of tailings ($SiO_2+Al_2O_3/CaO+MgO$), the decisive criterion of the suitability of raw materials for manufacturing of all types of basalt products (basalt continuous fiber, basalt wool, cast basalt) was calculated to be 1.4–1.6. These values are clearly insufficient to recommend the original tailings as raw materials for production of high-quality basalt fiber.

Gravity separation is used to improve the quality of the original tails. The simulation of this process was carried out in the laboratory on a screw lock with a 160 mm gutter diameter. The original crushed tailings clasts were beneficiated using a screw conveyor with the production of several products: concentrate (4.5–7.5%), final product (60–80%) and tailings.

Concentrate contains mainly titanomagnetite, ilmenite, and sulfides and small amounts of gold, tinstone, intermetallic compounds of Cu and Zn, native copper, and arsenic sulfides. Traces of gold (<0.25 mm) are found in a concentrate, they are present as Ag- or Cu, Ag-gold, usually with traces of mercury (Osovetsky, 2016). Titanomagnetite can be easily separated by magnetic separation and added to the main product of the enterprise. The final product is mainly composed of pyroxene, while the tailings generated by gravity separation are feldspars. An additional microprobe analysis of pyroxene grains revealed thepermanent presence of scandium (0.1%). Stepanov et al. (2017) proposed the baseline data for designing a pilot plant with an annual processing capacity of up to 10,000 tons of tailings to produce high purity (99.5–99.95%) scandium oxide in the amount of 1000 kg per year.

The simulation of the melting process of the above-described crushed tailings produced by wet magnetic separation was carried out using a synchronous thermal analyzer. Experiments showed that the tailings products are characterized by a small weight loss during heating (<5%). The melting of the rock-forming minerals begins at 1200–1223°C with an endothermic effect being in the range between -479 and -731 J/g of rock.

Subsequent cooling of the resultant melt at a step of 10 °C/min was carried out to study its crystallization. Analysis of the cooling curves revealed the effect of unwanted nucleation and crystallization during cooling that produces heterogeneities in the products. This effect occurs at a temperature of 1150–1162°C.

Thermal testingof some products generated during gravity separation showed that they are more suitable raw materials for the production of basalt fiber. In particular, the melting of the tailings from gravity separation is accompanied by a lower endothermic effect (decreased by about 23%) and less pronounced crystallization during cooling compared with a similar process developed for the original product.

The quality of raw materials produced by gravity separation of the original tailingswas improved due to removal of refractory components (e.g. titanomagnetite, chromite, ilmenite), a decrease in the content of iron, chromium, titanium and a number of other unwanted admixtures. At the same time, sulfides containing both harmful sulfur and toxic elements (e.g., arsenic) were removed from tailings.

Conclusions

Our study demonstrates the advances of the Perm University in the integrated use of raw materials, solving problems of tailings disposal and environmental protection. The price of the proposed technology should take into account the cost of tailings disposal. In the near future, EVRAZ KGOK plans to launch the development of a new ore deposit. In view of the long-term iron ore mining activity in this area, the company needs additional land plots for tailing dumping and disposal. It is planned to build a new tailings disposal site, but its area is limited by its proximity to the river. In connection with this, the application of relevant multi-tonnage and environmentally friendly technologies of tailings disposal are of prime interest.

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