THE INFLUENCE OF SHOTCRETE ON FLUORSPAR FLOTATION AND ITS REMOVAL BY SENSOR BASED SORTING

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ABSTRACT

The use of shotcrete is a mandatory means for rock support and therefore for safety in many underground mining operations. If shotcrete gets into the flotation feed though, it can negatively influence the flotation process. This especially occurs when sublevel stoping, cut-and-fill or room-and-pillar methods are applied because as the mining face moves on, formerly applied shotcrete layers are mined together with the ore.

As shotcrete does not differ significantly from fluorspar ore in its physical properties it gets moved through the comminution process and is fed to the flotation plant like the ore. To prove the influence of shotcrete on the flotation process, a laboratory test series was conducted at the Unit of Mineral Processing (AMR) of the RWTH Aachen University. The shotcrete grade of the flotation feed was varied between 0 and 10% through addition of pure shotcrete. Flotation parameters and also reagent dosage were held constant apart from the addition of the pH regulator, which was dosed to reach a constant pH of 8 at the flotation start. Results showed that with increasing shotcrete grades in the flotation feed the fluorspar recovery as well as general mass recovery decreased. The enrichment factor of Fluorspar also decreased with increasing shotcrete grades in the feed.

In an effort to eliminate the shotcrete contamination of the flotation feed, a feasibility study for use of sensor-based sorting prior to the comminution process was conducted. Rock sorting not only reduces the bad influence of shotcrete on the flotation process, but also reduces comminution costs.

KEYWORDS

Shotcrete, Fluorspar, Sensor-based Sorting, Flotation
INTRODUCTION

Shotcrete is used in underground mining on a regular basis. It is used for rock support and therefore to increase safety in the underground mining environment. In mineral processing the presence of shotcrete can cause difficulties for example in the concentration processes. In flotation the highly sensitive reagent mixtures can be disturbed by the chemical activity of shotcrete and therefore recovery rates and selectivity of the process can suffer.

Shotcrete is a special form of concrete which is applied pneumatically with high velocities and is compressed by its impact energy. Since the process is especially suitable for work in difficult environments and overhead areas, it is established in underground mining for many years. Shotcrete is not only applied in pre-processing of the mines, but particularly of use for cut and fill, as well as room and pillar mining methods. There it is used to secure excavation chambers. When the mine face is secured with shotcrete and subsequently the mining continues, the applied shotcrete will automatically be mixed with the ore.

As mines get deeper and therefore rock support has to be increased, also the use of shotcrete will be increased. In a German fluorspar mine the ore is separated from the waste by density separation with a subsequent flotation stage. As shotcrete does not differ much from fluorspar in its density, most of the shotcrete is fed to the flotation stage with the ore. In preparation for flotation the feed gets ground in wet ball mills, which further liberates the shotcrete and increases its surface. The now much more reactive shotcrete affects the pH of the pulp, absorbs collector and therefore disturbs the flotation process. Losses in recovery rates were observed when shotcrete contents in the feed were high.

The study at hand proves a relation between shotcrete content in the flotation feed and decreased recovery rates in the product. In addition to proving the cause of the recovery losses, a way to reduce the shotcrete content in the feed is presented.

SHOTCRETE IN MINERAL PROCESSING

A study about the influence of shotcrete on selectivity and recovery on the nickel flotation was already performed in 2000 at Strathcona Mill of XStrata Nickel (when the study was performed, Strathcona Mill was part of Falconbridge, which was acquired by Xstrata Nickel in 2005). The study concluded that particularly young shotcrete, which was younger than seven days, had a negative influence on nickel recovery. In presence of 1% shotcrete in the feed nickel recovery dropped from 98% to 96,5% compared to the baseline test. As cause of the influence of the contaminant lime was identified. Lime seemed to cover particles with a hydrate layer and increase the pH value above the optimal level. The influence was avoided by adjusting the pH by adding sulfuric acid as regulator (Kanhai, 2000).

In 1971 the influence of concrete on the flotation of lead and zinc ore was analyzed. Recoveries of lead and zinc were negatively influenced by the presence of cement. As reason for the influence again the increased pH was identified. The loss of lead recovery was caused by a simple relationship to pH. Like in the case of nickel flotation the use of acid to regulate pH was the solution to overcome the lead losses. In contrast to that the pH regulation itself did not improve the zinc recovery. Surface scrubbing of the zinc particles in presence of copper sulfate however seemed to help reducing the losses (Gauci & Cusack, 1971).

THE INFLUENCE OF SHOTCRETE ON FLUORSPAR FLOTATION

To evaluate whether recovery rates could be fixed by the mere regulation of the pH, the Unit of Mineral Processing of RWTH Aachen University conducted a test series with varying shotcrete contents in the flotation feed. Within the test series a representative sample of the flotation feed of the plant was taken. In the following paragraphs this fraction is referred to as “ore”. Additionally, a sample of pure shotcrete was selected which was found on the feed stockpile for the processing plant. The shotcrete was crushed in a laboratory cone crusher and milled in a laboratory rod mill with 100% circulating load, while being...
screened at 250 µm between milling stages. With this procedure a grain size distribution was created that is comparable to the one the industrial milling plant would have created. This fraction will be referred to as “shotcrete”.

**Characterization of the feed**

Figure 1 shows the particle size distribution of the raw ore in comparison to the comminuted shotcrete fraction. Shotcrete and ore were analyzed individually since they were mixed in a later stage of the test preparation. The $d_{50}$ of the shotcrete fraction is at about 120 µm and about 17% are below 20 µm. For the ore fraction the $d_{50}$ is slightly finer at about 80 µm. The fines fraction below 20 µm contains about 15% of the total mass.

![Figure 1 – Grain size distribution of untreated flotation feed and shotcrete before flotation](image)

X-Ray fluorescence (XRF) analyses of the ore fraction showed a fluorspar (CaF$_2$) content of about 60% and a calcite (CaCO$_3$) content of about 1%. Quartz (SiO$_2$) was detected with 26% and the barite (BaSO$_4$) content was about 8%. The shotcrete content in the ore fraction is related to the calcite content, since no calcite is naturally present in the examined deposit. The shotcrete content of the flotation feed was calculated to be about 3%. This shotcrete content will be the baseline for the study at hand.

**Flotation Test Preparation**

For the test series different artificial mixtures of shotcrete and ore were prepared. The test series included tests with shotcrete contents of 0% (baseline test), 0.5%, 1%, 1.5%, 2%, 3%, 4%, 6%, 8%, and 10%. Before the samples were mixed, all material was dried in a drying furnace at about 105°C. Each test was performed with a total sample mass of 1 kg and the same flotation chemistry as in the industrial plant was used. For the pulp tap water with a pH of about 7 was used. Oleic acid was taken as collector, fermented lignin sulfonate as depressant and an alkyl phosphoric acid as frother. Regulation of pH was done with diluted hydrofluoric acid (10% HF). All reagent dosages except the pH regulator were held constant throughout the test series. The dosage of the pH regulator was varied as much as necessary to reach a pH value of 8 ± 0.2 when the flotation process was started.

![Figure 2](image)

Figure 2 shows the CaF$_2$ and the CaCO$_3$ Grade in the feed at varying shotcrete contents. The CaF$_2$ content stays quite stable at about 64% until the shotcrete content reaches 1.5%. At 2% shotcrete in the feed, the CaF$_2$ grade decreases by about 1% and continues to drop constantly at increasing shotcrete contents, reaching 57–60% at shotcrete contents of 8–10% in the feed. The CaCO$_3$ content develops...
contrary to CaF₂, which is not surprising since it is contained in the shotcrete. Without shotcrete contamination in the feed, the CaCO₃ content is about 0.6%. Even though no Ca except CaF₂ is present in the deposit, this can be explained by the fact that a shotcrete contamination may have occurred before sampling of the flotation feed. That is why the flotation feed was defined as baseline and only artificial contamination with shotcrete will be taken into account in this study. With increasing shotcrete contents the CaCO₃ content also increases up to about 2.3% at a shotcrete content of 10% in the feed.

![Graph showing CaF₂ and CaCO₃ grade of the feed at varying shotcrete contents](image)

**Figure 2 – CaF₂ and CaCO₃ grade of the feed at varying shotcrete contents**

### Flotation Test Procedure

The test series was performed in a “KHD Humboldt Wedag MN935/5” laboratory flotation cell, equipped with a 2 L vessel. The revolution of the rotor was 1750 rpm; the air flow was set to about 1 L/min. The pH was continuously measured with a “WTW pH320” pH-meter. Conditioning of the pulp started with 15 minutes attrition of the particle surfaces in plain water. Within that time the pH was already regulated, if necessary, to get to about 8. After 15 minutes depressant was added and conditioned for another 5 minutes. After that collector and frother were added and conditioned for another 5 minutes. pH regulation continued throughout the complete conditioning time. Then the flotation process which lasted 5 minutes was started. During flotation the froth was paddled off the surface manually and pH was not regulated any longer. After flotation was finished, pH of the froth product and the residue in the flotation vessel were measured individually. The process was performed identically for each test.

### Flotation Test Results

After being dried in a drying furnace at about 105°C the product masses were recorded and the samples were prepared for XRF analysis and wet chemical analysis. Via XRF analysis the Ca content of each sample was determined. In the wet chemical analysis CaF₂ was determined. By subtracting the Ca content of CaF₂ from the complete Ca content, the CaCO₃ content of each sample can be calculated.
In Figure 3 the recovery of CaF$_2$ and CaCO$_3$ at varying shotcrete contents is shown. CaF$_2$ recovery seems to be quite stable between 94 and 96% for shotcrete contents of up to 2.5%. In presence of higher shotcrete contents, recovery of both, CaF$_2$ and CaCO$_3$ decreases constantly. When the feed is contaminated with 3% shotcrete, CaF$_2$ recovery is down to about 90% and decreasing almost linearly to about 60% when 10% shotcrete is in the feed. The fact that CaCO$_3$ recovery also decreases with increasing shotcrete underlines the fact that flotation did not work well anymore when the shotcrete contamination was increased. Mass recovery of the froth product also decreased from about 70% when 3% shotcrete were in the feed to about 45% with a contamination of 8–10%.

These observations can be explained by the development of the pH of the products. The pH of the feed was constantly around 8 when flotation was started. pH values of froth and waste were increasing with increasing shotcrete contents. This leads to the conclusion that alkaline parts are solved out of the shotcrete during flotation which may lead to a worsened flotation performance.

In Figure 4 the enrichment factor of CaF$_2$ at varying shotcrete contents in the feed is shown. A shotcrete content of 0.5% in the feed does not seem to influence the enrichment negatively. It rather seems to increase the enrichment, but this statement would have to be confirmed by some more validation tests. The negative influence of higher shotcrete contents however can easily be seen in the figure, as the enrichment factor decreases from about 1.37 when no shotcrete contamination is present to about 1.28 when 10% shotcrete are in the feed. In combination with the fact that the waste fraction always had a higher pH than the froth product fraction, it gets obvious that excessive shotcrete contamination leads to a hardly controllable pH and therefore does have a negative influence on the flotation behavior.
One of the questions that arose during the test series was, whether the pH regulator would be the reason for the poor flotation results when higher shotcrete contents were present. Obviously the more shotcrete was added to the feed, the more HF had to be added to regulate the pH to 8. A possible solution could be to change the pH regulator in order to increase flotation efficiency. Furthermore, it is likely that an adjustment of the collector dosage could help reduce the negative influence of the shotcrete. A test series to cover that question has not been performed yet. For the present study however, it was decided not to change the flotation chemistry to tackle the problem of shotcrete in the flotation feed. The problem of the shotcrete contamination is that it does not occur continuously and on a constant level, but happens in short peaks, where high shotcrete contaminations occur, but also vanish as quickly. Experiences in the past have shown that short term adjustments of the flotation chemistry, that are changed back and forth in a short period of time, lead to unstable flotation results. A change in the collector dosage could also change the required depressant and frother, which in turn could lead to downstream effects in e.g. filtration processes.

Hence the idea was to address the shotcrete contamination earlier in the processing scheme so it would not even get to the point that flotation was influenced. The plant feed should be analyzed by means of sensor based sorting (SBS) and the major shotcrete content should be extracted before it even got to the first concentration stages. This would also have the advantage that early separated shotcrete would not pass through the complete processing plant avoiding unnecessary milling.

**SENSOR BASED SEPARATION OF SHOTCRETE FROM FLUORSPAR ORE**

Sensor-based sorting (SBS) includes all applications where physical properties of single particles are detected contactless by a sensor, a sorting decision is made by an IT unit and the particles are separated by a mechanical process (Wotruba & Harbeck, 2010). Basic requirement for the detection of different materials are differences in detectable physical properties, like color, conductivity or density. A main characteristic of SBS is the decoupling of sorting criterion and separation mechanism. This also allows for simultaneously detecting multiple sorting criterions by using more than one sensor (Riedel & Wotruba, 2005).

Sensor-based sorters consist of three main elements: material feed and singling of every individual particle in the first part, detection in the middle and separation in the last part of the sorter (Schubert, 1996; Killmann, 2009). A schematic drawing of a sensor-based sorter is shown in the figure below:

**Figure 4 – Enrichment factor of CaF\(_2\) at varying shotcrete contents**

![Figure 4](image_url)
Figure 5. The material is fed to a vibratory feeder, which transfers the particles to a faster conveyor belt. The singling is reached by the change of speed that occurs during the transition from the vibratory feeder to the conveyor belt. After singling, the particles are being detected by the sensors (in the case of Figure 5 an EM-sensor and an optical sensor). The signal produced by the sensor gets processed in an IT unit, which also decides if a particle should be rejected or accepted, and then again transfers a signal to the air nozzles, where separation is done (Wotruba, 2006).

![Figure 5 – Schematic drawing of a belt type sensor-based sorter (Source: Wotruba, 2006)](image)

Identification of a Suitable Sensor for the Separation of Shotcrete and Fluorspar

For the separation of fluorspar and shotcrete different approaches seem suitable. In Figure 6 a picture of some samples of the shotcrete fraction and of the ore fraction are shown. For the shotcrete fractions coarse darker particles in a grey matrix are characteristic. In contrast to that colors of particles in the ore fraction vary widely. Furthermore, the shotcrete that was used in the operation at hand usually contains metal wire which could be detected by a metal detector.

![Figure 6 – Exemplary shotcrete and ore particles for sensor-based separation](image)

To test the different sensors 50 samples of each fraction were analyzed with a color sensor and a metal detector.

Sensor Test: Color Sensor

To test the applicability of a color sensor to separate ore from shotcrete, pictures of all 100 particles were taken. The pictures were then analyzed by an image processing tool of a sensor-based sorter.
The tool analyzes the picture on base of color classes which have to be defined beforehand. It then creates a false color picture and assigns every single pixel to a specific color class. To be able to separate two materials from each other, the user has to define material classes which differ from one another. The user has to predefine material properties with regard to the color classes, so the different material classes can be explicitly distinguished from each other.

In Figure 7 four exemplary particles of the shotcrete fraction and of the ore fraction are shown. The labels “SB” indicate shotcrete particles, the label “E” stands for ore particles. On the left side of the figure, the unmodified photos of the particles are shown. On the right side, the corresponding false color images are visible. Three color classes were defined. Red and green pixels correspond to ore particles and grey pixels indicate shotcrete. Particles “SB 18”, “SB 19”, and “SB 20” are clearly in the shotcrete fraction. Particle “SB 17” however only contains very few pixels of the “Shotcrete” color class. The challenge was to find a suitable limit value to define the “Shotcrete” material class.

As only three of fifty shotcrete particles contained less than 20% pixels in the “Shotcrete” color class and only one ore particle contained more than 20% “Shotcrete” pixels, this value was used as threshold for the separation. With optical sorting 98% of the ore particles and 94% of the shotcrete particles were allocated to the right fraction. This sounds very promising, but optical sorting also has its disadvantages: Particle surfaces have to be clean for detection, which means that a scrubbing stage before sorting is imperative. Furthermore, lighting quality in industrial scale sorters often is not as stable and clear as on a laboratory photo stand. In order to identify a second option when pilot tests with optical sorting would fail, another sensor was tested in pilot scale.

**Sensor Test: Metal Detector**

For the conductivity test all 100 rock samples were individually fed to a pilot sorting machine in the laboratory of the AMR in Aachen. This procedure was repeated three times and the rocks were turned
in between tests, so a one sided metal content would be detected as well. Since ore particles do not contain any metal the sorting criterion was more than no metal contained.

As expected, in the ore fraction every test detected 0% conductivity. In the shotcrete fraction 25/150 tests detected 0% conductivity as well. Out of these 25 measurements 21 were clear assignments of 7 particles. Each of these particles did not contain any metal wires and therefore showed 0% conductivity in all three measurements. One particle showed 0% in two of three measurements and two particles showed 0% in one of three measurements. Depending on how these particles are located on the belt they would be incorrectly allocated.

The metal detector identified 100% of the ore particles and 80-86% of the shotcrete particles correctly. A positive effect of this sensor is that no valuable particles will be lost, while the shotcrete content will be significantly reduced. This technology only works when metal wire is contained in the shotcrete. Finer particles have a lower probability of containing metal wires and are therefore harder to detect. Other technologies exist where shotcrete is supported by fibre mats or bolts. In those cases, obviously a metal detector would not be able to detect shotcrete however it could be detected by optical sorting.

**CONCLUSIONS**

Shotcrete is used in underground mining on a regular basis. When it is mined with the ore and fed to the processing plant it may cause problems downstream. It was shown that excessive shotcrete contamination has a negative effect on the flotation process of fluorspar ores. The alkaline nature of the shotcrete causes the pulp to exceed the optimum pH of 8. Regulation of the pH with hydrofluoric acid only reduced the negative influence up to a shotcrete content of 3% in the feed. When the shotcrete content was further increased, CaF$_2$ recovery as well as the enrichment factor of CaF$_2$ continuously decreased. If an optimization of the flotation chemistry or the use of another pH regulator could tackle the problem still has to be determined. In the current study however the problem was addressed in another way. The applicability of sensor-based sorting to separate shotcrete from raw ore before comminution was tested. 100 rock samples were analyzed with both, an optical sensor and a metal detector. It can be concluded that both sensors, were able to identify the majority of the particles correctly. SBS seems suitable to reduce the shotcrete content of the feed as much as necessary to eliminate the negative effect shotcrete has on fluorspar flotation.

**REFERENCES**


