

Geotechnical behaviour of spent ore – impacts of metallurgical factors

R. Rimmelin¹, C. Vergara²

1.

Global Practice Lead Geotechnical (MAusIMM), BHP, Brisbane QLD 4000. Email: Rigoberto.RP.Rimmelin@bhpbilliton.com

2.

Principal Geotechnical Engineer, SRK Consulting, Santiago RM 7550011. Email: cvergara@srk.cl

ABSTRACT

Heap leach pads are composed of mined ore, usually crushed, disposed on liners to be processed with leach solutions, and the tail of the process is called “spent ore” which are then transported by conveyor belts to be disposed into dumps. It is often to observe stability problems in these dumps, that could affect the equipment working on it and the continuity of the whole mine process. These problems are related to an excess of water content at the spent ore, therefore the operational efforts are focused onto control this geotechnical parameter.

This work presents the results of different geotechnical laboratory testing, using samples of spent ore of a mining operation in the north of Chile. In the last 10 years, 3 campaigns have been made to get samples. Valuable information was obtained to identify how specific operational/metallurgical factors could affect the geotechnical behaviour of the spent ore. Special attention is given to the decision to change the metallurgical process adding salt to the heap leach process and its impact to its hydraulic conductivity.

Historically, the process has been based on the leaching of oxides and sulphides materials, in separate campaigns, in which it is possible to observe different geotechnical response in the spent ore generated. Recently, it was implemented a new process in which the materials are blended and salt is added, to improve metallurgical performance in terms of recovery. This change generate impacts in the dump, since the geotechnical parameters are affected; decreasing hydraulic conductivity in about one order of magnitude (explained by the salt added).

Changes are shown in the geotechnical parameters of the spent ore, considering that the mining source is the same, and how the operational process and dump design are affected.

INTRODUCTION

Since the year 2008 to present, it has been done several geotechnical exploration campaigns for spent ore of this case of study. This work presents the analysis of the results of the laboratory testing already done, to estimate the index properties of the spent ore, shear strength parameters, deformation parameters and hydraulic conductivity, to show the impacts on the spent ore dump design based on metallurgical process changes.

The samples were obtained from several leach pads modules (sulphides and oxides) and from the spent ore dump related to the site of this case study. Figure 1 shows the particle size distribution of this materials, classified as clay gravels (according to USCS) with maximum size of 3.81 cm (1,5”). By the other hand, fines percentage (under #200) varies between 10% and 30%.

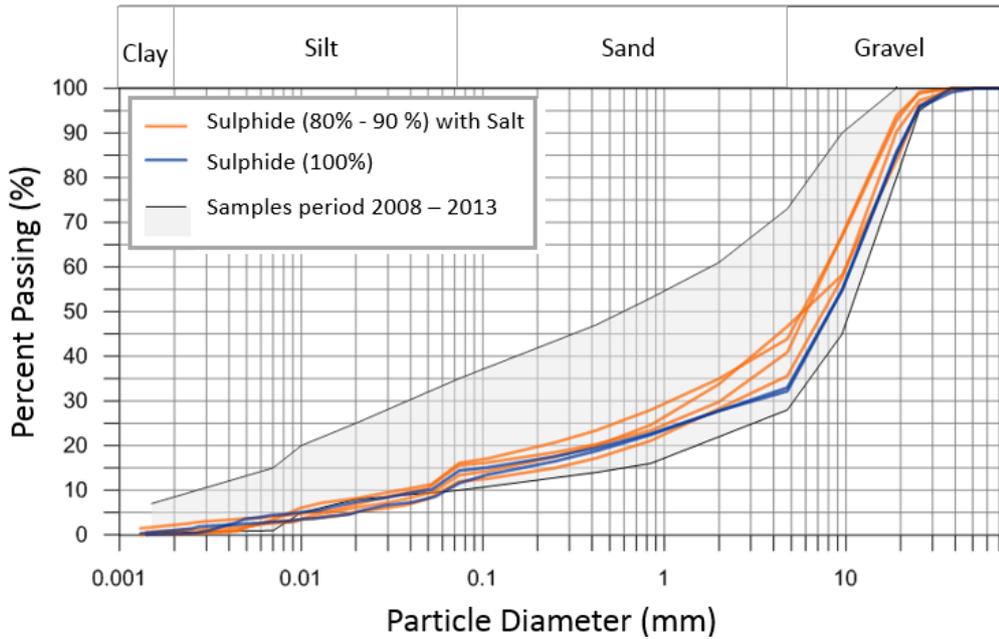


FIG 1 – Spent Ore Particle Size Distribution

Particle size distributions of the period between 2016 and 2017, are in the low range of the band, that is, are the coarsest historical materials of the site (2008 to date). This result is expected since current materials are based on a high sulphide proportion (80%), and a lower part is oxide (20%).

It should be noted that particle size distributions presented in the Figure 1 were obtained using the dry method, that is, fines under #4 (5 mm) were washed and therefore agglomerates destruction around gravels was minimized. By the other hand, when the wet method was used, that is, all fines were washed, then the content of fines is increased reaching out values of 29%; however, this last value is considered referential since the behavior of the material is related to the agglomerated state in the spent ore dump.

Figure 2 shows the plasticity chart where is observed that the fines of these tested materials are classified as clays or slimes of low plasticity (CL, CL-ML).

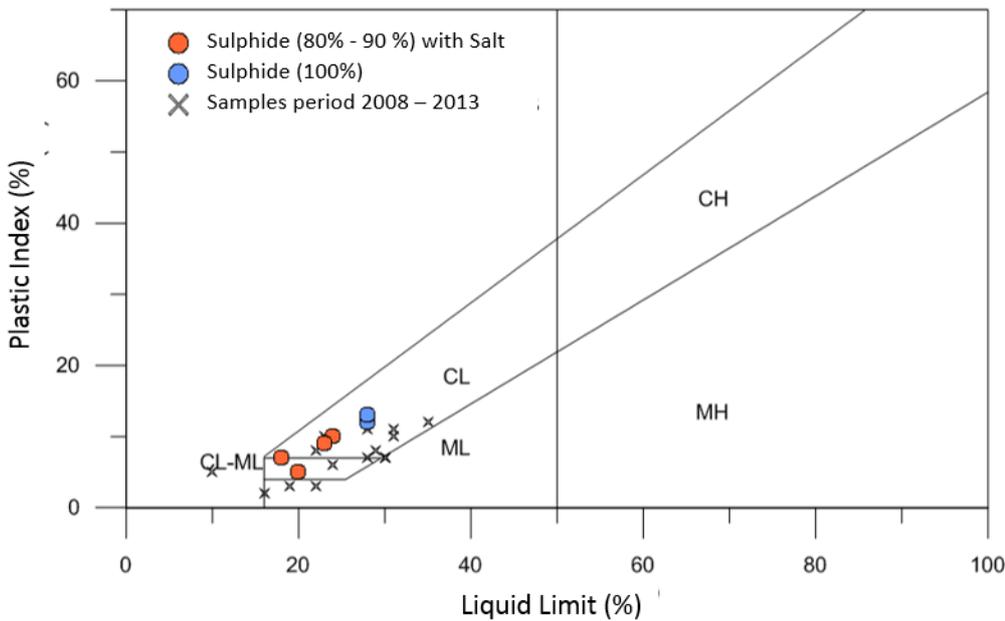


FIG 2 – Plasticity Chart

GEOTECHNICAL CHARACTERISATION

Following is presented the results of the main geotechnical testing made to the spent ore samples, such as shear strength triaxial (drained and undrained), oedometric testing and hydraulic conductivity of the materials.

Shear strength

Shear strength of the materials was assessed using consolidated isotropic undrained testing (CIU), made in saturated conditions. Considering the particle size distribution of the samples, testing was made in test samples of 15 cm of diameter by 30 cm of height. The test samples were prepared on remolded material for a loose condition with relative density values of 40% in average, and a compaction rate based on the modified Proctor test of 70% in average.

Figure 3 shows the steady state lines obtained from the CIU testing results, for a sample with salt (orange line) and for other sample without salt (blue line). The Table 1 shows the corresponding values of shear strength parameters for each type of material (spent ore) and its size distribution characteristics. These parameters were determined considering the maximum deviatoric stress (q).

Table 1 shows also historical results obtained for spent ore, in which it is possible to observe that the shear strength parameters are closely correlated to the fines/gravel percentage of the samples. The higher amount of fines the lower internal friction angle, and, by the opposite, the higher amount of gravels the higher internal angle friction is obtained.

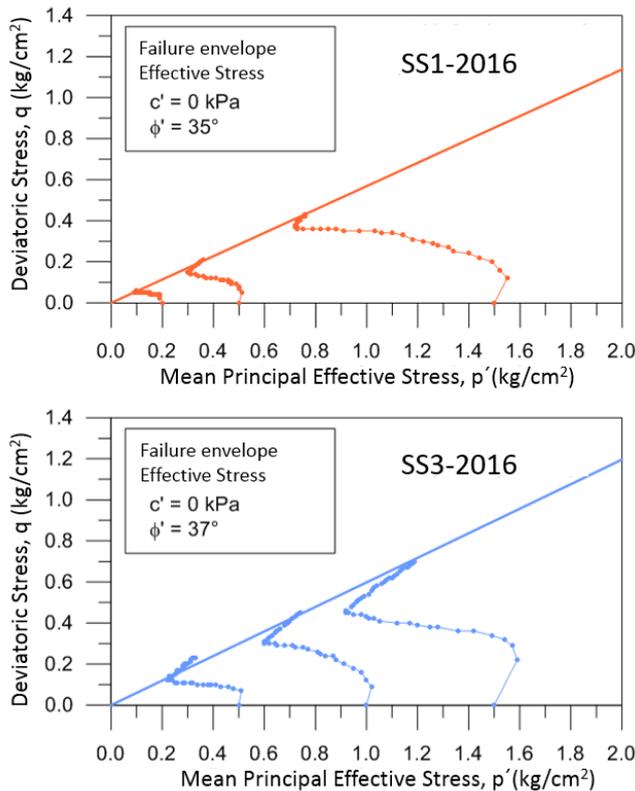


FIG 3 – Typical Steady State Line Effective Stress – CIU Triaxial Test

TABLE 1

Shear Strength Parameters - CIU Triaxial Test

Sample	USCS Classification	%Gravel	%Fine	ϕ' (°)
OS1-2008	SC	34	27	29
OS2-2008	GM	55	14	36

OS1-2012	SC-SM	32	22	31
OS1-2013	GM	62	15	37
SS1-2013	GM	72	15	39
SS1-2016	GC	56	16	35
SS2-2016	GP-GC	64	12	36
SS3-2016	GP-GC	67	13	37

Note: OS: Oxide Sample / SS: Sulphide Sample (>80% Sulphide)

In addition to saturated triaxial test, CIU tests in Unsaturated conditions were performed to understand the impacts of water content on Undrained strength (Total Stress) of spent ore. Figure 4 shows the internal friction angles obtained, measured in total stresses, as a Function of water content, for each material/sample tested. It is possible to observe an inverse correlation between water content and shear strength parameters (friction angle).

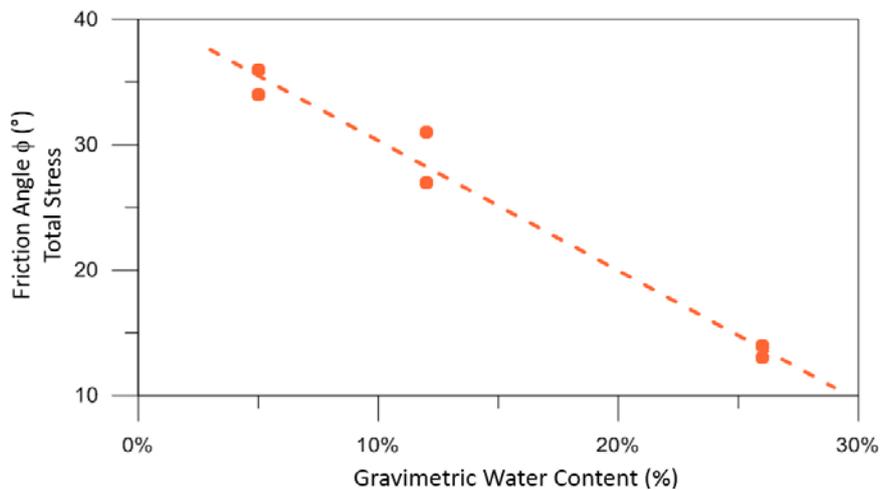


FIG 4 – Friction Angle (Total Stress) for CIU Unsaturated Triaxial Test –Results of SS1 and SS2 Samples 2016

Oedometric testing and Saturated Hydraulic conductivity determination

Densification of the spent ore due to static loads was quantified based on oedometric testing (one dimensional consolidation), for 6 samples compacted at the same initial density, and saturated to a load of 49 kPa. In this kind of testing, a vertical load is applied to correlate with void ratio, and at the same time, void ratio is correlated with the dry density. By the other hand, the vertical load can be linked to a certain average height of the dump. By this way, a maximum vertical load of 785 kPa is applied during the test, and equivalent to a 50 m height.

Additionally, during the execution of the oedometric testing, it was determined the saturated hydraulic conductivity after each load increment. Thus, using the same oedometric test equipment, was measured the saturated hydraulic conductivity at a rigid wall mold based on ASTM D5856. The results are presented in Figure 5, in which it is possible to observe an increase in hydraulic conductivity for higher values of void ratio, that is, for a loosening condition of the spent ore.

It is important to highlight that spent ore hydraulic conductivities of 2016 (including salt) are lower than the spent ore studied in the previous years (2008-2013) for the same compaction condition. Besides, it was observed that a degradation of the hydraulic conductivity as a function of densification is more evident for the spent ore of 2016 than the previous period of 2008-2013, according to the statistical trend of data. However, it is needed to validate these results, for example doing tests with a sample with different salt concentrations and include hydraulic conductivity testing using flexible wall to control the saturation of the samples and avoid preferential flows at the boundary of the test sample (rigid wall).

According to Lopez (2012), the addition of hypochlorite, in the process of agglomeration, doesn't affect significantly the results of hydraulic conductivity of the spent ore, and for acid solution is the same result. This

last effect is observed in Lopez (2012) in which testing with different pH values and distilled water were made, and any significant difference was not observed. Because of this, it is recommended to do geotechnical tests complementary to metallurgical tests when changes are made in the metallurgical processes, mostly in early stages at the same time of column testing is made or when are built pilot plants to study the metallurgical performance.

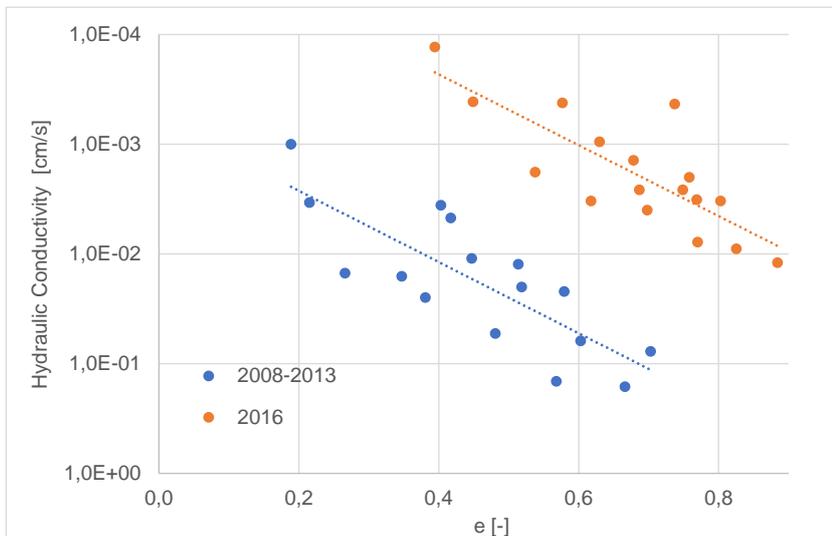


FIG 5 – Hydraulic conductivity versus void ratio

OPERATIONAL CONDITIONS AND DESIGN OF SPENT ORE DUMP

Since the year 2014 to present, the metallurgical process has been including the addition of salt (Sodium chlorite) in the agglomerate process stage (of the material coming from crushing), with the objective to improve the metallurgical performance in the leach pads. It was observed that relevant operational parameters like water content of the spent ore, before to be dumped, hasn't changed significantly because of the salt addition to the process. This way, water content of the materials, before dumping, varies in the range of 9% and 11%, during the period of 2015-2016. This range is very similar compared to period of 2008-2013, previous to the change in the process. Figure 6 presents a graph with values of water content between the years 2015 and 2016.

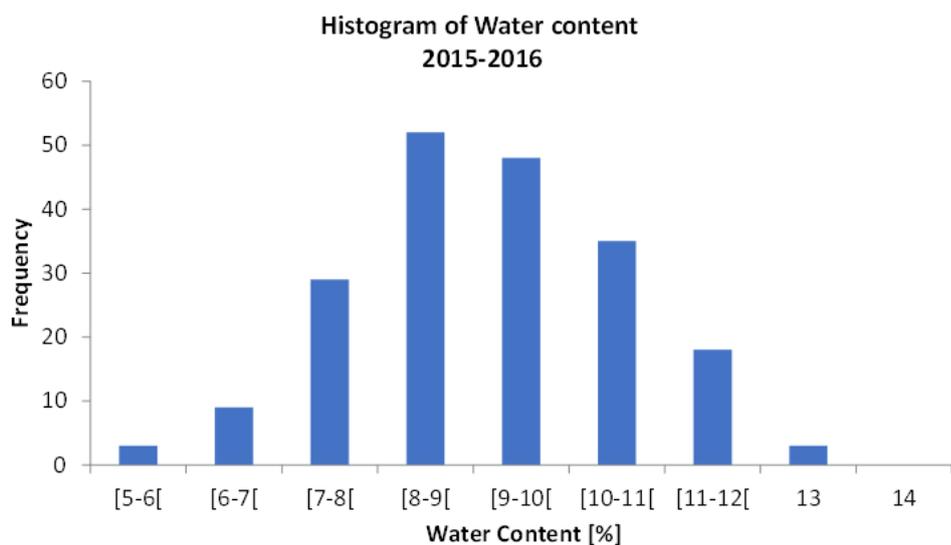


FIG 6 – Spent Ore Water Content 2015-2016

On the other hand the original dump design considered two types of material coming from the metallurgical process: oxides and sulphides. These materials were processed and dumped in separate campaigns. For this reason, the dump used to take into account the worse geotechnical quality (oxides) for design purposes.

The oxide material, with lower geotechnical quality, forced to include a retaining wall in the design based on waste from the mine, deposited in compacted layers, as shown in the Figure 6.

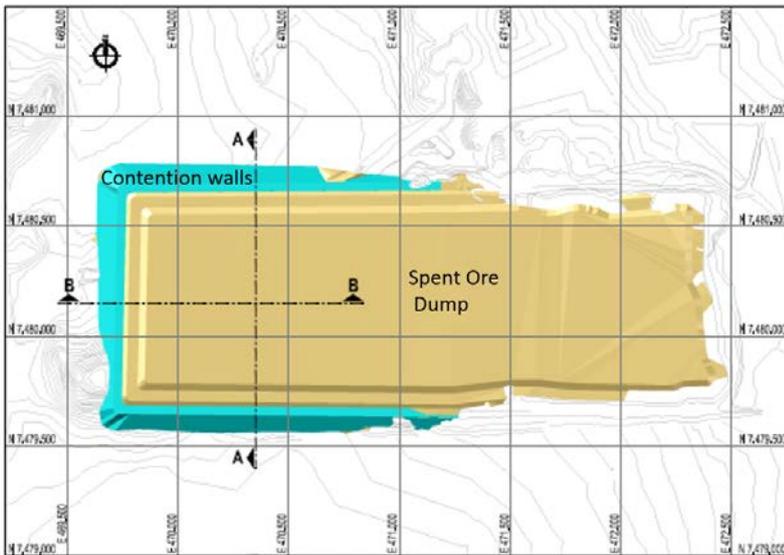


FIG 7 – Original waste (spent ore) dump design – Plan View

The new process involved a blend of both types of materials (oxides and sulphides) during the leach pad process, in a proportion 10-20% of oxides and 80-90% of sulphides, obtaining an improvement in the quality of the resulting material to be deposited in the dump. As can be observed in this work, the shear strength of the blended material with addition of salt, is similar to the before 100% sulphide material without salt.

Nevertheless, the addition of salt impacted the hydraulic conductivity showing lower values than previous 100% sulphides materials without salt. This element is important due to the impact on the stability of the leach pads and spent ore dumps, generating a more adverse phreatic level.

These results were included in the geotechnical assessments, whose combined effects resulted in better stability conditions, providing the opportunity to remove one of the retaining walls (based on waste material from the mine), increasing the dump capacity of spent ore (see Figure 8).

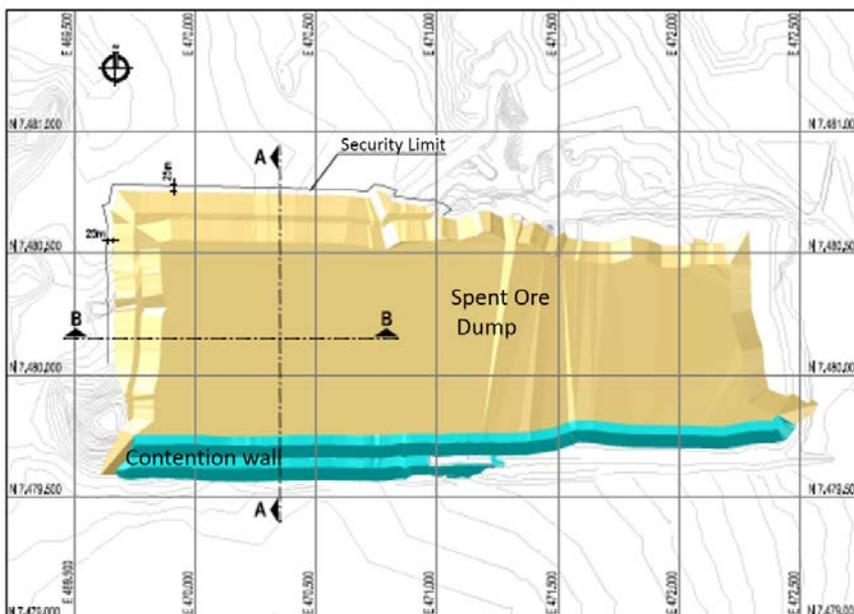


FIG 8 – Proposed waste (spent ore) dump design – Plan View

CONCLUSIONS

Based on the work developed, it was found the following main conclusions:

- The geotechnical characterization of the spent ore, shows us a material with high sulphide proportion (80%), and in most cases, with addition of salt. The particle size distribution of the tested material are similar between each other, and can be classified as the coarsest of the historical records between the period between 2008 and 2016.
- Based on saturated hydraulic conductivity measurements of the spent ore for different levels of densification, it was observed that samples with addition of salt shows lower hydraulic conductivity values than samples without salt, for the same levels of density. It is recommended do more research to test this effect in future campaigns of characterization, and reassess the irrigation rates used in leach pads, considering a lower hydraulic conductivity for materials with salt.
- Additionally, it is needed to consider hydraulic conductivity testing including flexible sample casing to avoid preferential flows in the boundaries of the test sample.
- It is important to take into account additional geotechnical testing before to implement changes in the metallurgical process, in early stages in which metallurgical testing (like testing columns) are made or during a pilot plant implementation/execution stage.

Operational controls of the spent ore after the leach pad process, are needed to obtain the particle size distribution in the following cases:

- Leach pads with oxides percentages higher than 20%
- Leach pads with fines (under #200) higher than 15%
- During the irrigation time, in which leach pads show water pools and/or slope sliding

Another operational controls are:

- Take measurements of soluble salt content.
- Permanent control of humidity (at least 2 times per day) of the spent ore in the dump.
- Includes spreadsheets or databases, containing information related to the spent ore behavior in the leach pads (hazard maps) and the content of humidity of spent ore before to be dumped.
- Identify contingency plans when an excess of humidity is detected in a leach pad when the resting time is achieved, such as:
 - Dispose a temporary dump for the wet material to provide additional resting time before to dispose in the final dump.
 - Blend wet spent ore with dry spent ore and/or waste mine material to generate a blended material with lower humidity.
 - Install piezometers in the spent ore dump to check the existence the formation of any phreatic level.

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