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Effect of increased vertical stress on the state of grains in tailings

Effet de l'augmentation du stress vertical sur l'état des grains dans les résidus miniers

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ABSTRACT: The mining industry has experienced rapid growth, leading to the accumulation of substantial mine waste, commonly referred to as tailings. Tailings are typically stored in tailings storage facilities, conventionally consisting of an impoundment surrounded by tailings dams. The construction of tailings dams can involve various methods, with the upstream method being commonly used in the industry. It is crucial to comprehend the long-term mechanical and geochemical behavior of deposited tailings to ensure the safety of upstream constructed tailings dams. The mineral composition, particle size distribution, and particle shape all affect the susceptibility to particle breakage or physical alteration. Therefore, there is an interest in understanding how grain size and grain shape relate to mineral composition and potential particle breakage to ensure the understanding of the long-term mechanical behavior. This study focuses on characterizing deposited tailings from various depths and investigates the impact of increased vertical stress on tailings, particularly examining the potential for crushing effects. The findings highlight the importance of considering these factors for a comprehensive understanding of tailings behavior and their implications for the long-term safety of tailings dams.

RÉSUMÉ: L'industrie minière a connu une croissance rapide, entraînant une accumulation substantielle de rejets de concentrateur, communément appelés résidus miniers. Les résidus sont généralement stockés dans des parcs à résidus, traditionnellement constituées d'un bassin entouré de digues construites de résidus. La construction de digues avec des résidus se fait avec différentes méthodes, la méthode amont étant couramment utilisée dans l'industrie minière. Il est crucial de comprendre le comportement mécanique et géochimique à long terme des résidus déposés pour garantir la sécurité des digues de résidus. La composition minéralogique, la distribution granulométrique et la forme des particules ont toutes une influence sur la susceptibilité des particules à se briser. Par conséquent, il est essentiel de comprendre comment la variation de taille et de forme des grains est liée à la composition minéralogique et à la possibilité de rupture des particules afin de garantir le comportement mécanique des digues à long terme. Cette étude se concentre sur la caractérisation des résidus déposés à différentes profondeurs dans la digue et examine l'impact de l'augmentation de la contrainte verticale sur les résidus, en particulier en ce qui concerne le potentiel d'effets de broyage. Les résultats mettent en évidence l'importance de prendre en compte ces facteurs pour une compréhension complète du comportement des résidus et de leurs implications pour la sécurité des digues de résidus à long terme.

Keywords: Tailings; mineralogy; particle size distribution; particle shape.

1 INTRODUCTION

The mining industry, vital for modern life, has seen rapid growth and thereby increasing notably the mine waste (Lyu et al., 2019). One type of mine waste is tailings and this leftover material is typically stored within impoundments surrounded by tailings dams, which are often built and raised up using tailings itself (Villavicencio et al., 2014).

Tailings dam construction can be classified into three main methodologies: upstream, centreline and downstream construction methods. Traditionally many tailings dams have been built by the upstream method and in this approach, embankments are placed on top of previous deposited tailings, implying that the tailings impoundment will eventually become part of the dam body and foundation for future embankments. Many upstream facilities have demonstrated satisfactory performance; however, this construction method is generally considered the least reliable (e.g., Fourie et al., 2022).

Intuitively, it is essential to understand both the mechanical and geochemical behavior of tailings to be able to perform safety assessments of upstream tailings dams over time (e.g., Vick, 1990).

According to Vick (1990), there could be a potential change among some of the intrinsic properties of the tailings related to the long-term behavior, which thereby likely modifies the mechanical behavior. Some changes could be related to particle size distribution (PSD) and particle shape, as they adapt to new state properties (stress state and void ratio). Potentially crushing, particle breakage or degradation can occur implying a change in the PSD and particle shape. Zhang et al. (2020) emphasize that the magnitude of change in PSD and particle shape is strongly dependent of the mineralogic composition.

Bhanbhro (2017) looked at the crushing for uniform sized tailings (i.e. tailings sorted out in different group gradations) and exposed them to stepwise increased vertical stress from oedometer test making a comparison of the strength parameters, particle shape and breakage analysis.

The aim of this paper is to investigate the potential for particle breakage or physical alternations in form of change in the PSD on a whole tailing gradation, exposed to increased vertical stress (i.e., from slow and stepwise increased overload due to continued deposition). By conducting a comparative analysis, the study provides inputs that may enhance the understanding of tailings behavior under increased vertical load, although from the results presented herein it is understood and highlighted how mineralogical analysis must be merged into the analyses of PSD and particle shape analyses for better understanding.

2 METHODOLOGY

This study involved the analysis of disturbed samples extracted from a borehole within a tailings impoundment in northern Sweden, reaching a depth of approximately 40 m. Laboratory work was conducted on 4 samples collected from the borehole at varying depths, separated by approximately 10 meters each. These samples were designated as A (4.2 – 4.5 m), B (15.0 – 15.4 m), C (24.5 – 25.0 m), and D (33.5 – 34.0 m) as shown in Figure 1.

The samples underwent initial characterization, including PSD, particle shape and mineralogy. Subsequently, they were subjected to vertical stepwise loading through oedometer testing up to 640 kPa. Finally, another PSD characterization was performed on the oedometer tested samples.

The samples exhibited a PSD of sand and silt grains, with a fines content (<0.063 mm) ranging between 10 and 30%. The maximum grain size identified within the samples was 2.00 mm.

Samples were reconstituted using tamping methodology and the non-linear undercompaction method by Jiang et al. (2003). Additionally, one sample (D) was also prepared as a slurry to investigate possible effects of soil fabric and particle arrangement in the oedometer results.

For particle shape and mineralogical analyses, a qualitative assessment was done for particles greater than 0.063 mm through imaging using reflected light and scanning electron microscopy (SEM), respectively. SEM analysis was performed only in 2 out of 4 samples (A and B) since it was not possible to complete the test in all samples as expected due to some technical equipment problems.

Initial PSD samples were determined through wet sieving and sedimentation methods, while a dynamic image analysis was executed after oedometer testing using a Camsizer XT equipment. This equipment uses LED light sources and high-resolution cameras to scan particle collective injecting compressed air. This approach emerged as an alternative due to the limited amount of sample obtained after oedometer testing and potential uncertainties in the results when employing traditional sieving.

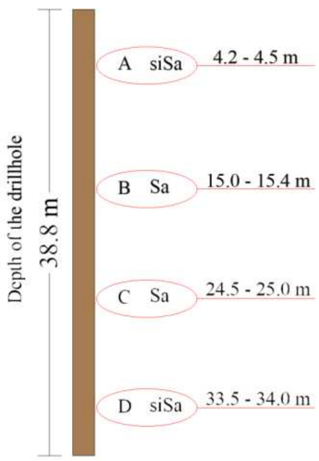

Figure 1. Drillhole and sampling schema.

3 RESULTS

3.1 Particle size distribution

The study presented herein focus on the changes in particle size distribution comparing before and after oedometer testing. The findings showed that the incremental stepwise loading produced minor and, in some cases, negligible variations in PSD. These variations were primarily observed in the coarser particles, leading to an increase in fines content. The most noticeable deviations occurred between sieves with apertures of 1.00 mm and 0.063 mm. Figure 3 and Figure 2 displays the PSD for sample A and D, correspondingly. Samples B and D showed the most prominent changes at the 0.125 mm sieve size with an increase of 2.93% and 3.83% compared to their original PSD, and belonging to decrement at the 0.5 mm sieve size about 0.48% - 1.71%. Sample A displayed the lowest variation in fines after testing, with a maximum deviation of 0.46% at the 0.125 mm sieve.

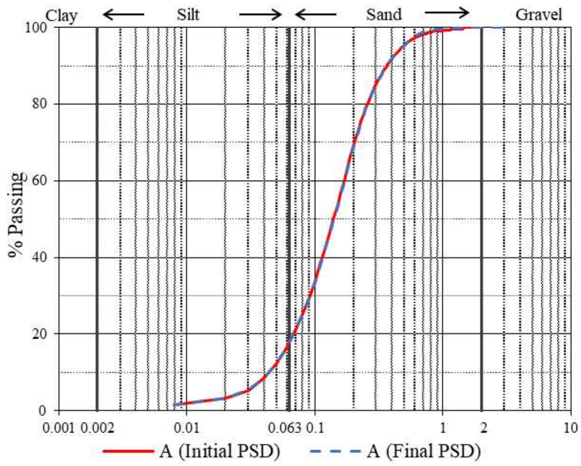

Figure 2. PSD sample A before and after testing.

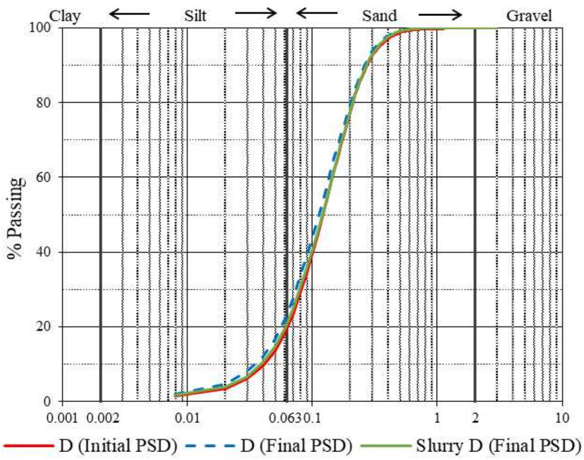

Figure 3. PSD sample D before and after testing.

In this study the change of PSD before and after oedometer testing are relatively small. However, the results are consistent in that all samples exhibited an increment of finer particles after oedometer testing. These results agree with the findings of Bhanbhro (2017), who for the tailings with the same origin showed that in uniform gradings coarser particles are more prone to breakage than finer particles. The uniform gradings of large particles (1-0.5 mm) in Bhanbhro (2017) exhibited a decrement around 14% at the 0.5 mm sieve. Thereby, it is clear that the uniform particles showed a more distinct physical alteration than the whole gradation tested samples in this study. If magnitude of alteration in PSD is disregarded all samples (from both studies) indicate that larger particles are more prone to physical alterations under vertical loading. This may be attributed to the presence of internal fractures and stress concentration at particle edges, that are more present at larger particles. The reason to only a small change in PSD for the whole grading samples in this study are likely attributed to finer particles filling out the voids between the coarser particles.

Slurry sample D (green in Figure 2) exhibits reduced susceptibility to potential physical alteration of particles, with a maximum deviating increment of 1.31%, compared to its initial PSD at sieve 0.063 mm. Corresponding deviating increment for tamped sample D was 3.58% (blue in Figure 2). This result suggests that slurry samples display another interlocking behavior between particles, where finer particles protect the larger ones more effectively than tamped samples.

3.2 Mineralogy

The mineralogical composition of particles is generally similar among the analyzed samples, but variations in element concentrations are evident as shown in Figure 4 and Figure 5. Assessing the elements concentration on particles, the most common minerals identified in both samples include mica, feldspar, plagioclase, and quartz. However, other residual minerals are also found. Sample A exhibited gangue minerals such as sorosilicate, K-feldspar, and apatite, while sample B contained iron, hematite, pyrite, illite, and biotite.

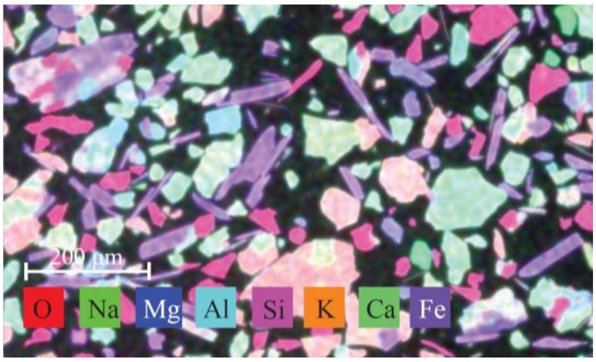

Figure 4. SEM analysis of sample A, depth 4.2 – 4.5 m.

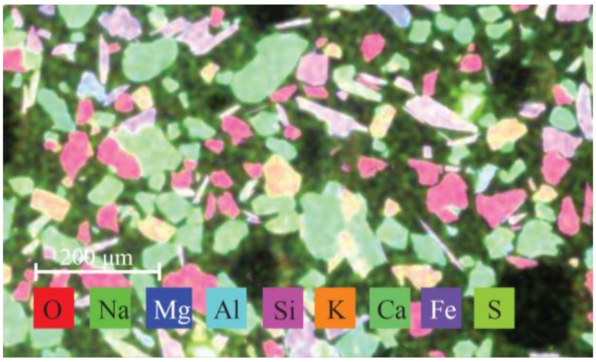

Figure 5. SEM analysis of sample B, depth 15.0 – 15.4 m.

3.3 Particle shape

Qualitative analysis of the results obtained from reflective light imaging and SEM analysis was performed using the roundness qualitative scale developed by Powers (1953). The tailings in this study have particles with a low sphericity shape where larger tailings particles are mostly subangular. Meanwhile the smaller the particles become, the shape turns into a combination of subangular and very angular. The black holes observed in Figure 4 and Figure 5 are voids that became trapped during sample preparation; however, they did not affect the interpretation.

4 CONCLUSIONS

This study shows that change in PSD of silty-sandy tailings tested in oedometer are evident, although the changes are small to neglectable. Tamped samples were found to be more susceptible to changes in PSD after oedometer testing compared to slurry samples. Furthermore, the magnitude of the change in PSD are smaller in this study than the similar, but uniform graded, tailings tested by Bhanbhro (2017).

Consequently, this implies that the characteristics of the soil fabric is important when consider the potential for physical alterations of particles due to increased vertical stress. The presence of fine particles and the manner they fill the voids and confine the larger particles clearly influence the vulnerability for particle breakage or physical alterations of particles. To some extent this is intuitive, if one considers that the particle-to-particle contact, stress distribution as well as the possibility of particle rearrangements directly are affected by how and to what extent the fine particles connect to the larger particles.

It is essential to assess the entire particle size distribution when evaluating susceptibility to breakage in a particular tailings sample. In addition, this study has shown that soil fabric can affect susceptibility to particle breakage or other physical alterations due to increased vertical stress. Neither tamped nor slurry prepared soil fabric in the laboratory might be the accurate replicate of field conditions. It is a complex topic and among several factors the in-situ soil fabric varies due to deposition methods, sedimentation, consolidation, saturation conditions, geochemical processes, etc.

Depending on tailings mineralogy and particle shape composition, there might or might not exist risk of change in PSD due to particle breakage or physical alterations which in the end likely will influence the mechanical behavior. Quantification and detailed analysis of the potential for particle breakage is complex. A step forward is believed to link the particle shape and particle size to the mineralogic composition as differences in hardness will affect the change in PSD. This, then can increase the understanding for the potential to physical alterations of particles and thereby the susceptibility of tailings to suffer from change in mechanical behavior over time.

5 ACKNOWLEDGMENTS

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