Proceedings of the XVII ECSMGE-2019
Geotechnical Engineering foundation of the future
ISBN 978-9935-9436-1-3

doi: 10.32075/17ECSMGE-2019-0614

XVII European Conference
ECSMGE 2019
Reykjavik
on Soil Mechanics
and Geotechnical Engineering

Consolidation of copper mine tailings

Consolidation des résidus de mine de cuivre

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ABSTRACT: Thickened tailings surface deposition, settling and consolidation are affected by grinding, mineralogy and mechanical thickening performance variations. The behaviour of such tailings is complex and affected by several factors. They usually start as a viscous fluid and after deposition they settle and consolidate, gaining stiffness and strength. The volume reduction associated with the consolidation is usually relevant, and therefore one of the key parameters for the capacity design of tailings storage facilities.
In the present paper the results of a laboratory study of the settlement and self-weight consolidation behaviour of tailings are presented. The purpose of this study was to evaluate, in detail, the effects of the mechanical thickening process, prior to tailings deposition, in the consolidation parameters. The tailings were thickened to different solid particles content and deposited inside settling columns. After settlement and consolidation under self-weight had finished, the columns were dismantled to allow the determination of the void ratio along the column height. In a separate but identical setup, the tailings in the bottom of the column were used for oedometer testing.

RÉSUMÉ: Les dépôts en surface, la sédimentation et la consolidation des résidus de mine épaissis sont affectés par les variations de performance du broyage, de la minéralogie et de l'épaississement mécanique. Le comportement de ces résidus est complexe et dépend de plusieurs facteurs. Ils commencent généralement par un fluide visqueux et, après dépôt, ils se déposent et se consolident, gagnant en rigidité et en résistance. La réduction de volume associée à la consolidation est généralement très importante et constitue donc l'un des paramètres clés de l'analyse de la capacité des installations de stockage de résidus.
Ce papier présente les résultats d'une étude en laboratoire sur le comportement des résidus en matière de tassement et de consolidation par effet du poids propre. Le but de cette étude était d'évaluer en détails les effets du processus d'épaississement mécanique, avant dépôt des résidus, sur les paramètres de consolidation. Les résidus ont été épaissis à différents degrés et déposés dans des colonnes de décantation. Une fois le tassement et la consolidation sous poids propre terminés, les colonnes ont été démantelées pour permettre la détermination de l'indice des vides le long de la hauteur de la colonne. Dans une configuration séparée mais identique, les résidus au bas de la colonne ont été utilisés pour des essai à l'oedomètre.

Keywords: Mine tailings; thickening; consolidation; drying effects

1 INTRODUCTION

The generation of mine tailings is inevitable and, in most cases, corresponds to a high percentage of the material extracted from the ground. All that amount of waste must be deposited adequately. During many years, mine tailings were deposited without control, creating critical situations for the environment and public health (Blight, 2010). In many cases, capital appreciation paradigms limit the resources available to develop or improve sustainability in the mining industry. Consequently, the mine tailings are commonly managed using conventional methods of deposition inside mud containing reservoirs, while cements and materials extracted from other locations are used to fill underground tunnels and galleries already explored. However, more recently, there has been an increase in the number of mine sites where the tailings are processed in order to reuse all that can be useful (Jewell, 2010). Examples include the reuse of process water, as well as using tailings for underground fill.

Scientific and engineering advances have provided an enormous contribution to the efficient and productive mine tailings management. As a result, the regulators have been licensing more holistic approaches to waste management problems, one of which is the paste tailings deposition (Jewell e Fourie, 2010).

The present paper presents a case where the deposition technique changed from underwater pulp to thickened tailings deposition (paste). The advantages of that change and its effect in the tailing's properties are addressed in this study.

In the tailings management facility under study, the change from underwater pulp deposition to thickened tailings deposition afforded several environmental and geotechnical advantages, that can be summarized as follows (Fourie, 2012; Raposo 2016):

- thickened tailings, having a lower void ratio, occupy a smaller volume, allowing the extension of the lifetime of the tailings deposition site for several years;
- thickened tailings can be deposited forming gentle slopes, increasing the volumetric capacity of the deposition site;
- by having lower deformability and higher strength, thickened tailings contribute to long term stability, after the closing of the tailings storage facility;
- the thickening process allows the recovery of large amounts of water, which is reused for the industrial process;
- there is a lower amount of water to manage and consequent lower structural environmental risks inherent to potential breakages, since the amount of free water in the reservoir is greatly reduced;
- segregation ceased to exist, so the deposit becomes less permeable and geochemically more stable.

2 TAILINGS THICKENING AND TRANSPORT

As shown in Figure 1, the process of thickening the tailings consists in removing some of the water from which they are made of (Slottee, 2014). In the present case, the tailings arrive at the decision site with a solids content of 25% (the solids content corresponds to the weight of solid particles divided by the total weight). They are transferred to a storage tank which feeds the thickeners. At the entrance of the thickeners the flocculant is added, at the approximate rate of 30 grams per ton. The amount of flocculant can be adjusted according to the changes in the tailings particles size distribution. The flocculant has the function of aggregating the solid particles, favoring their sedimentation.

Each of the two thickeners used in this tailings management facility is 18 m wide and 17 m high. The tailings remain inside the thickeners for about 10 hours. The thickeners underflow has an average solids content of 70%. The underflow is pumped at low pressure by a horizontal centrifugal pump located at the base of each of the thickeners. These primary pumps carry the

tailings from the bottom of the thickeners to the positive displacement pumps. The latter, working at high pressures, are responsible for transporting the tailings through a network of pipes that covers the entire reservoir. Usually two deposition points are active at the same time, which are changed every 2-3 days, depending on the needs.

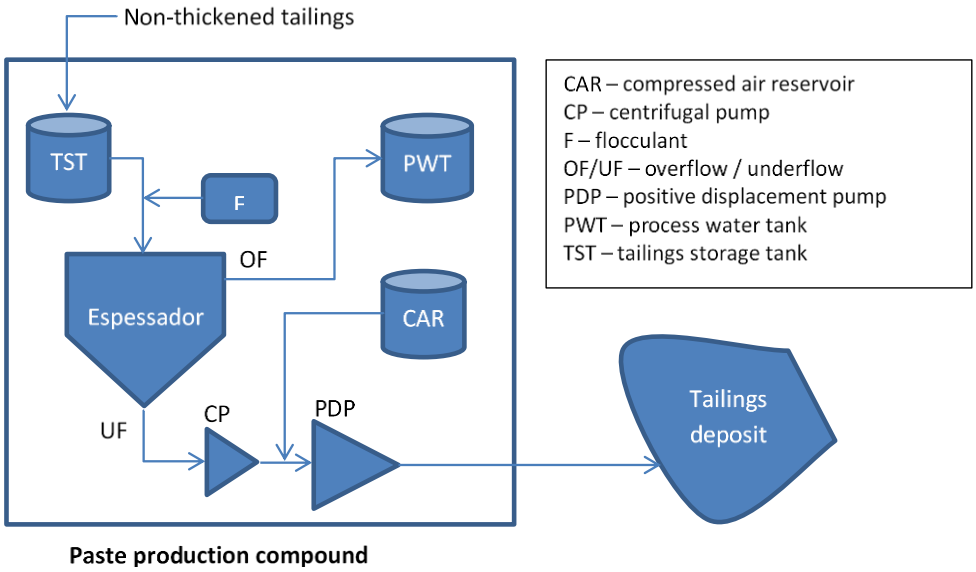


Figure 1 Tailings thickening and transport

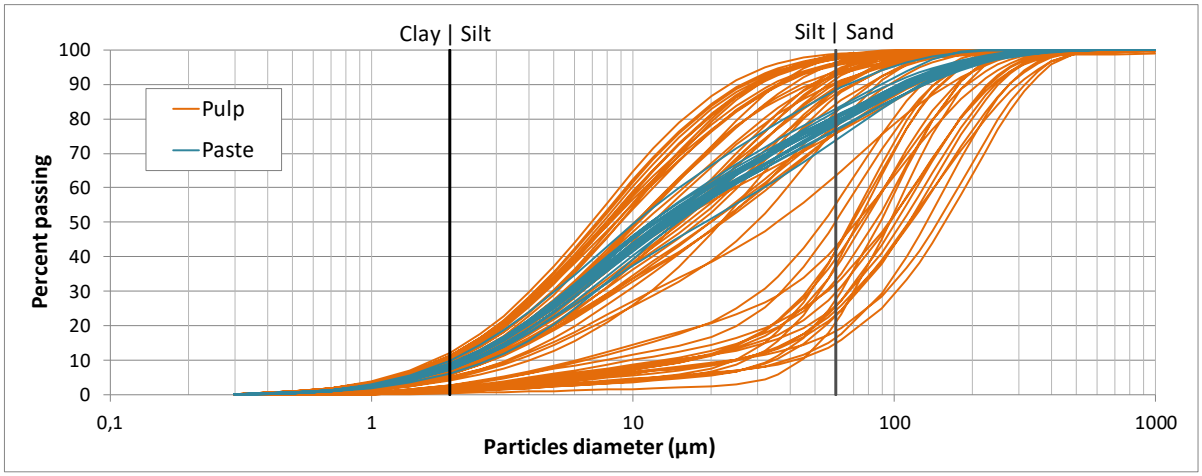


Figure 2 Sieve analysis of the non-thickened tailings used in underwater deposition (pulp) and the thickened tailings (paste), adapted from Raposo *et al.* (2014)

3 EFFECTS OF THE THICKENIGN IN THE GRAIN SIZE DISTRIBUTION

One of the crucial aspects with respect to the tailings behavior is the grain size distribution. In the graph of Figure 2 it is possible to see a large set of curves determined in various samples of tailings. The regularity found in the thickened tailings (paste) contrasts with the large segregation found in the non-thickened tailings samples (pulp).

One of the great advantages of paste deposition, in comparison with conventional underwater deposition, is precisely the fact that segregation is very limited or even inexistent. The absence of segregation promotes the reduction of the liquefaction susceptibility of the tailings, due to a more compact arrangement of the particles of different sizes.

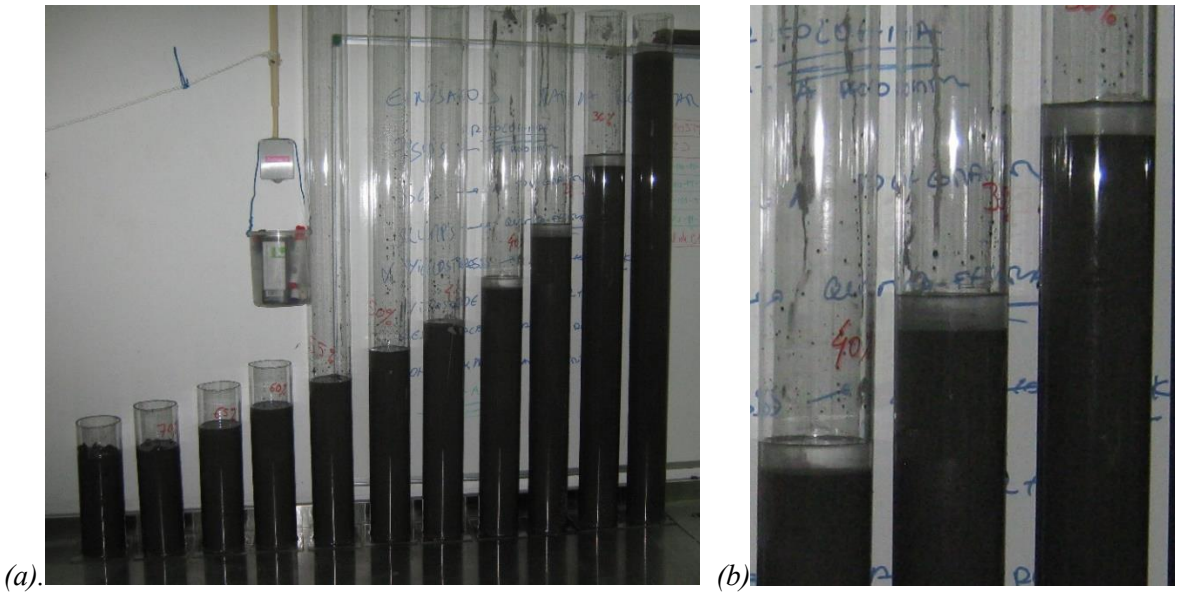
From another point of view, the absence of segregation also promotes the reduction of the general permeability of the deposit, since horizontal lenses of sandy material cease to exist, which, as it is well known, are preferred ways of percolation. The lower permeability results in a smaller infiltration and, consequently, in the reduction of the seepage water. At the same time the degree of saturation of the deposit is increased, which, in the case of reactive materials, as the ones in the present work, is of vital importance to the geochemical equilibrium of the deposit.

4 SEDIMENTATION TESTS

With the purpose of studying the effects of the thickening process, the tailings were tested using sedimentation columns. In these tests, the tailings were thickened to different degrees before being deposited inside acrylic columns with inner diameters of 74 mm, as shown in Figure 3. Each column contained 1200 g of solid particles and different amounts of water, so that the solids content varied between 25 and 73%. Having a specific density of 3.5, the effective vertical stress in the bottom of the columns is 1.9 kPa.

Figure 3a shows all the sedimentation columns, just after the deposition of the tailings in its interior. Figure 3b shows a detail of the columns with solids content of 40, 35 and 30%, shortly after deposition. It can be observed the formation of a layer of “clean” water on the top of the tailings.

The settlements of the tailings surface were measured at regular intervals, until the end of sedimentation. At that point, the average void ratio was calculated by the final height of the tailings within the column, resulting in Figure 4. This graph shows the dependence between the degree of thickening, translated by the solids content, and the average void ratio at the end of the sedimentation. There is a clear correlation between these two parameters. The higher the solids content at the time of deposition, the lower the void ratio after the sedimentation. This effect is nonlinear and tends to grow with the degree of thickening progresses. Increasing the solids content from 25 to 55% changes the formation void ratio from 1.9 to 1.7. At the other end of the scale, the small change in the solids content from 70 to 73% leads to a reduction on the void ratio from 1.3 to 1.1.



(a). *(b)*

Figure 3 Sedimentation columns: a) general view; b) detail of the columns with 40, 35 and 30% solids content

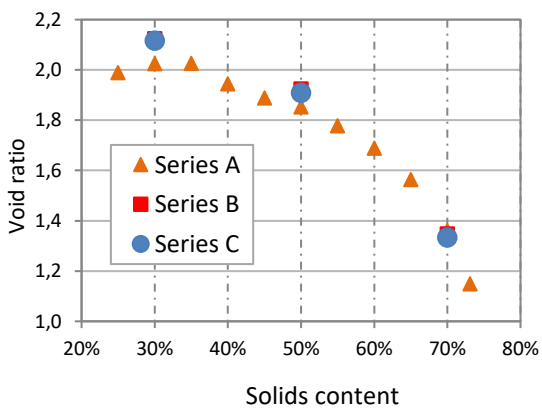


Figure 4 Average void ratio at the end of sedimentation

5 OEDOMETER TESTS

The preparation of samples for the oedometer tests was done in a similar way to the sedimentation tests. The tailings were thickened to different solid contents (30, 50 and 70%) and then deposited inside acrylic columns. After the deposition, a sample from the bottom of the columns was used for oedometer testing. In order to evaluate the effects of surface drying, a fourth sample with a solids content of 70% was placed in the oedometer cell but was subjected to 5 wetting/drying cycles before the application of the load stages.

Figure 5 shows the compressibility curves obtained in the four oedometer tests. There is a substantial difference in the initial void ratio of each sample. In fact, although the initial effective stress of the three samples was the same, the tailings initial thickness restricts the sedimentation process. This difference in the initial state translates into differences across the various load stages. Even at high stresses, 1600 kPa, the void ratio of the three samples is different, showing how important the initial thickness is. This behavior is also seen in the fourth sample, where the lower initial void ratio, caused by the wetting/drying cycles, causes a shift in the compression curve. The compression

index ranged from 0.29, on the non-thickened sample, to 0.22 in the sample thickened to 70% solids content and subjected to drying/wetting cycles.

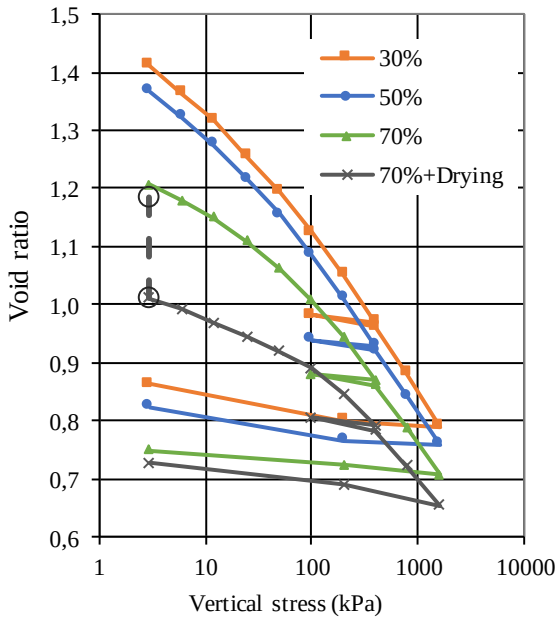


Figure 5 Compressibility curves from oedometer tests

6 CONCLUSIONS

The experimental results presented in this work show some of the effects of thickening on the behavior of the tailings. The samples obtained in situ clearly show two families of particle size distribution curves. Samples of the non-thickened tailings exhibit a typical dispersion for underwater deposited materials, with segregation. In contrast, particle size distribution curves of thickened tailings samples form a narrow band, showing the absence of segregation.

The volume occupied by the tailings is a crucial aspect of any deposition facility. In this context, sedimentation tests showed the major advantages of thickening: as the degree of thickening increases, the volume occupied by the tailings after deposition becomes successively smaller. The results from oedometer tests have emphasized this assumption, showing that the thickened tailings have a lower void ratio when compared to non-thickened tailings, irrespective of the applied vertical stress, and therefore whatever the thickness of the deposit might be.

7 ACKNOWLEDGEMENTS

The authors would like to thank the support from Instituto Politécnico de Viseu.

This work was financed by: Project POCI-01-0145-FEDER-007457 - CONSTRUCT - Instituto de I&D em Estruturas e Construções - financed by Fundo Europeu de Desenvolvimento Regional (FEDER), though COMPETE2020 – Programa Operacional Competitividade e Internacionalização (POCI).

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