

Tailing Mixing of filtered cake with coarse rejects for Co-disposal (Mineral Processing and Extractive Metallurgy)

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SUMMARY

The co-disposal of filter cake with coarse rejects represents an evolving approach in tailings storage, driven by the Global Industry Standard on Tailings Management (GISTM) to ensure safe storage in perpetuity and improve water efficiency. Despite hesitance to shift to filtered dry stack methods, co-disposal has garnered significant interest due to successful plant trials. The dewatering operations and geotechnical properties of the materials involved are well understood. However, successful co-disposal requires efficient blending and transportation systems.

Mixing liquids and dry solids is relatively straightforward and backfill operations have been mixing wet cake with slurry on a small scale. For large-scale operations, where dry cake from pressure filters must be homogeneously blended with coarse rejects, the properties of the cake can represent a greater challenge need to be well defined.

During filtration within a filter the slurry moisture transitions from a dense paste through a plastic phase to a dry and friable consistency as water is removed. The more water that is removed the more complex the separation and generally this equates to higher pressures, large equipment and higher costs. Many backfill operation use vacuum filters where the cake is wet at a point where it is conveyable but still with a liquid consistency that is easily re-pulpable, well above an acceptable stacking moisture. Filtered cake for dry stacking must be dryer close to the optimum stacking moisture with solid characteristics beyond the plastic phase toward a dry and friable consistency to form a stable structure and to enable homogeneous mixing. This mixing is important as Waste rock has superior strength than tailings, filling the void between coarse waste is the target and layers of unmixed tailings may create weak points in the tailings storage deposit.

Two geotechnical industry measurements are the soil classification of Atterberg which can describe

the liquid limit and plastic limit and the Transportable moisture limit which describes a point where the cake will not liquify under vibration, similar to flow table. The moisture required for stacking lies somewhere between these areas of definition. Geotechnical design sets the target for placement however the cake solid characteristics for transportation and mixing are somewhat subjective without a systematic means of description.

This paper presents a series of lab trials aimed at characterizing the relationship between cake moisture and blendability. While free-flowing materials can be readily blended, filter cake is not free-flowing and often requires shear to reduce the cake lumps to a size suitable for disposal. The tests aim to establish a repeatable and simple method to characterize the amount of energy and time required to blend filtered cake with dry waste material.

The lab-scale test procedure involves several key steps. First, the range of testing should be linked to the geotechnical properties without necessarily having the site specific design criteria, it should be broad enough to cover a credible design range. For this reason the testing has been linked to a Proctor measurement. While co-disposal involves a mixture with waste the waste to cake ratio is not necessarily known and the waste may not be available. The testing should utilise a standard construction material to represent waste at a range of ratio's broad enough to cover mix designs.

Next, the production of cake and simulation of the discharge prior to transportation is conducted. The way that the material behaves under a standardised drop is evaluated by the size reduction. Then the behaviour of material under blending conditions with waste is evaluated.

Achieving a uniform mixture is essential for the successful co-disposal of filter cake with coarse rejects. The trials measure the homogeneity of the blend by analysing samples taken from different points within the mixture. This helps to identify any

inconsistencies and areas where further mixing may be required.

Overall, these lab trials provide valuable insights into the blendability of filter cake and the factors that influence its successful co-disposal with coarse rejects. The findings will help to optimize the mixing process, ensuring safe and efficient disposal of tailings while improving water efficiency and meeting the requirements of the Global Industry Standard on Tailings Management (GISTM).

1. Introduction

“The Global Industry Standard on Tailings Management strives to achieve the ultimate goal of zero harm to people and the environment with zero tolerance for human fatality.”

Tailings dams should be of a robust design taking consideration of the risks and consequences of their construction with well proven construction methods. One generally accepted construction material is the sand extracted from the tailings, to be an acceptable building material the sand must be compactable to a minimum density that will achieve the necessary structural strength and to have good drainage properties.

Due to the nature of generating and transporting the sand its initial saturation will be high and this needs to be reduced and controlled as saturation of the sand is as one of the greatest dangers for stability. While the sand itself must have an acceptable drainage property, a base drainage is required to remove excess water, and the structure needs to be controlled and measured to ensure the piezometric levels in the dam are at a safe level.

Governance of tailings dam management is increasing and while it is the operators of TMFs that have the primary responsibility for ensuring the safety of TMFs and for formulating and applying safety management procedures, as well as for utilizing technology and management systems to improve safety and reduce risks. The methodology of producing a construction material has inherent risks and quality is measured post deposition.

2. Goals

- A series of lab trials aimed at characterizing the relationship between cake moisture and blendability.
- The tests aim to establish a repeatable and simple method to characterize the amount of

energy and time required to blend filtered cake relative to the cake moisture.

3. Soil Classification

Atterberg limits tests are not required for this test program, but they help contextualize the range of testing. The guide for Atterberg testing of the liquid and plastic limits of soils sets the upper range of interest in filter cake behaviour.

In Atterberg testing, the moisture content at the transition from a semi-solid to a plastic state is the plastic limit (PL), the transition from a plastic to a liquid state is the liquid limit (LL) and less often reported is the shrinkage limit (SL) form the basis for soil classification.

For this test program, the target for cake properties will be on the dry side of the shrinkage limit, partially desaturated within the solid range (see figure 1). The percentage of moisture content at which the transition from a solid to a semi-solid state occurs is defined as the shrinkage limit (SL) in Atterberg tests. However, for this program, it will be defined as the "cake shrinkage limit" (CSL). This is the moisture content at the end of cake pressing, evaluated from cake analysis, where moisture is removed from the cake by displacement with air rather than compression. The area of interest is the solid desaturation zone, where the filtered cake contains three phases.

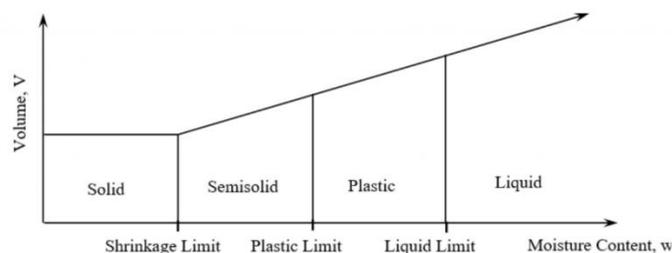


Figure 1 Qualitative positions of Atterberg limits on a moisture content scale

5. Specific Goals Filtration

With the filtration moisture targets set against the proctor results for this study, one representative type of tailing generated at the mining operation was selected. This differentiation will allow for the analysis of the effect of initial particle size distribution on filtering capacity, cohesiveness, fragmentation, and compaction response, key aspects in the design of co-disposal mixtures.

The samples selected for the study was fine tailing with p80 32 um

- Evaluate the effect of different operating conditions (pressure, pressing, and drying times) on the final moisture content of the filter cake.
- Determine optimal cycle times to achieve moisture levels close to the optimal geotechnical range of the soil.
- Establish filtration capacity in terms of productivity and air consumption.

Data Collection and Work Development

The biggest drivers of the project are operating cost are the capacity vs moisture performance.

Capacity moisture trade-off can be well simulated at pilot scale and the results would be accurately representing full scale operation. For the purposes of testing where most process variables are held constant with the exception of filter changes.

For the current scenario testing the number of variables should be reduced to enable a high-level decision on the best scenario. Process variables have a constant value for each day trial.

Tabla 1 Process variables

Variable		Value
Slurry pH	Constant value	10.5
Slurry temperature	Constant value	25°C
Slurry D.S. content	Constant value	60% w/w
Slurry P80	Constant value	32um
Pumping pressure	Constant value	6 bar
Pressing pressure	Constant value	12 bar
Drying air pressure	Constant value	6 bar

The test equipment for filtration test is shown below



Figura 2 MFP 0.3 test filter



Figura 3 Feed tank and pump - MFP 0.3 test filter

The MFP 0.3 test filter membrane pressure main dimensions are 1500 x 870 x 1300 mm (L x W x H). Weight of the laboratory filter is 520 kg.

- Filter area 0.27 m²
- Two-way filtration (1 chamber)
- Maximum operating pressure for the unit 16 bar
- The filter body is made of AISI316, AISI316L and AISI304
- Pressing plates are made of AISI316L
- Piping and valves are made of AISI316
- Filter plate pack and filter cake box are made of polypropylene
- Pressing diaphragm and sealing made of rubber
- Manually operated hydraulic unit does the closing of the filter. The operating pressure max. 700 bar
- Chamber height options: 25, 40,45, and 60 mm

Tests on the Metso FP 0.3 laboratory membrane filter press will result following data:

- Total length of cycle time including individual phases [min]
- Filter capacity [l/m²h or kg/m²h d.s.]
- residual moisture in the cake [%]
- solids in the filtrate [mg/l]
- air consumption [m³ /m²min]

Prepare a series of filter cakes of a minimum of 5 kg on a Metso FP0.3 or similar test filter. The cakes should have a moisture close to the optimum geotechnical soil moisture, at 85%, 90% and 95% of optimum soil moisture, one at optimum soil moisture.

Typical filtration tests are required to establish the cycles for the target moisture

Tabla 2 Filtration cycle time

Description	Moisture			
	85%	90%	95%	opp
Cycle time	85%	90%	95%	opp
Pumping time	X1	X1	X1	X1
Pressing time	X3	X3	X3	X3
Drying time	X5	X5	X5	X5

After filtration take the cake with minimum disturbance from the filter in preparation for the cake properties tests.

6 Flow diagram

The following diagram describes the proposed experimental flow to evaluate the technical feasibility of co-disposing filtered tailings with coarse aggregate (crushed rock) as a sustainable tailings management alternative.

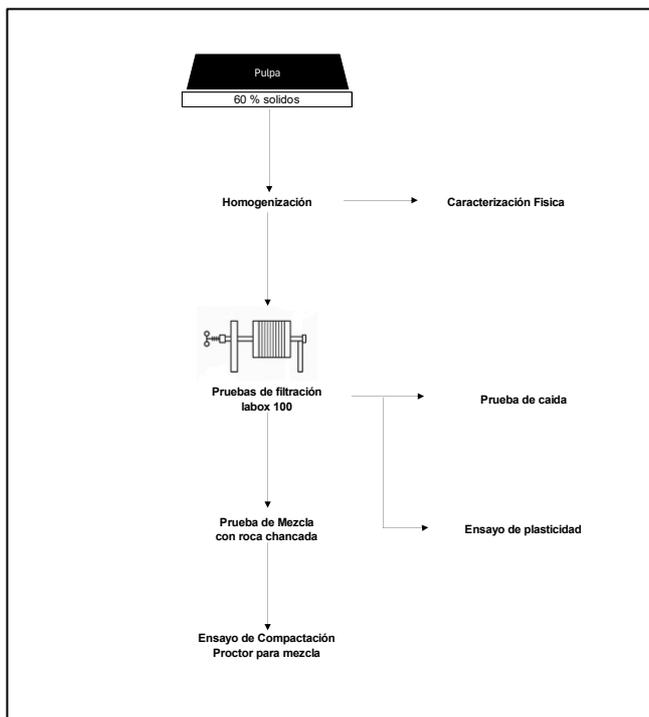


Figura 4 Flowsheet

7 Test results

7.1 Sample preparation

This preparation was carried out under controlled laboratory conditions, replicating typical plant operating parameters to ensure representative results.

A target solids concentration of 60% by weight was used, a value characteristic of operations that feed high-efficiency filtration systems.

This concentration allows for a realistic evaluation of material performance in subsequent stages such as filtration, tumbling, mixing, and compaction.

Tabla 3 Physical characterization

Variable	Value
Slurry pH	10.5
Slurry temperature	25°C
Solid Content (D.S.)	60% w/w
Slurry P80	32 um
Solid SG	2.77

Tabla 4 Chemical analyzes

Methods tested	Element	Unit	Value
2136	Fe	%	8.5
598	Ag	ppm	1.063
598	Al	ppm	>10000
598	B	ppm	89.49
598	Ba	ppm	62.72
598	Be	ppm	^b <0.40
598	Bi	ppm	47.95
598	Ca	ppm	4191
598	Cd	ppm	^b <0.080
598	Co	ppm	^b <0.40
598	Cr	ppm	143.8
598	Cu	ppm	797.0
598	Fe	ppm	>10000
598	Ga	ppm	64.14
598	In	ppm	^b <1.6
598	K	ppm	3671
598	Li	ppm	132.9
598	Mg	ppm	6604
598	Mn	ppm	764.5
598	Mo	ppm	^b <0.40
598	Na	ppm	447.9
598	Ni	ppm	^b <0.40
598	P	ppm	554.8
598	Pb	ppm	116
598	Sb	ppm	^b <0.80
598	Se	ppm	^b <1.2
598	Sn	ppm	60.33
598	Sr	ppm	9.5545
598	Te	ppm	^b <2.4
598	Ti	ppm	316.16
598	Tl	ppm	^b <0.80
598	V	ppm	27.77
598	Zn	ppm	544.5

Tested Methods

*2136 Test method for Iron by specific digestion – volumetric analysis

*598 Multi-element test method by ICP-OES with multi-acid digestion

Tabla 5 Mineralogical characterization

Nombre del mineral	Fórmula general	Resultado Aproximado (%)
Cuarzo	SiO ₂	57
Plagioclasa (Oligoclasa)	(Na,Ca)(Al,Si) ₄ O ₈	9
Clorita (Clinocloro)	(Mg,Fe) ₅ Al(Si ₃ Al)O ₁₀ (OH) ₈	9
Turmalina (Dravita)	NaMg ₃ Al ₆ (BO ₃) ₃ Si ₆ O ₁₈ (OH) ₄	8
Mica (Muscovita)	KAl ₂ (Si ₃ Al)O ₁₀ (OH,F) ₂	7
Mica (Flogopita)	KMg ₃ AlSi ₃ O ₁₀ (OH,F) ₂	4
Feldespatos - K (Ortoclase)	KAlSi ₃ O ₈	3
Montmorillonita	(Na,Ca) _{0,3} (Al,Mg) ₂ Si ₄ O ₁₀ (OH) _{2-n} (H ₂ O)	< L. D.
Apofilita	(K,Na)Ca ₄ Si ₈ O ₂₀ (F,OH) ₈ (H ₂ O)	< L. D.
Casiterita	SnO ₂	< L. D.



Figura 5 Sample preparation

7.2 Filtration test

Filtration tests were conducted using Metso's MFP 0.3 pressure filtration system, which simulates plant operating conditions in a controlled laboratory environment. This equipment is designed to evaluate cake performance under constant pressure, recording key parameters such as cycle time, filtration rate, and final cake moisture. The MFP 0.3 filter is shown below.

a) Equipment



Figura 6 MFP 0.3 test filter

b) Experimental Procedure

Filtration tests will be performed using the Labox MFP 0.3 laboratory filter press, under constant operating conditions and varying the cake moisture content to achieve different levels of relative compaction relative to the maximum dry density determined by the Proctor test.

Key filtration cycle variables:

- X1: Pumping time
- X2: Pressing time
- X3: Drying time

The following conditions are considered constant for each test, ensuring uniformity in the tests.

Tabla 6 Filtration variables

Variable	Value
Slurry pH	Constant value 10.5
Slurry temperature	Constant value 25°C
Slurry D.S. content	Constant value 60% w/w
Pumping pressure	Constant value 6 bar
Pressing pressure	Constant value 12 bar
Drying air pressure	Constant value 6 bar

c) Results

These results allow us to establish a target reference moisture 16.2%, which will be used as a baseline parameter for the design of drop tests, and bendability studies.

Furthermore, the data obtained are essential for projecting the performance of pilot- or industrial-scale filtration systems.

Tabla 7 Filtration test results

Variable	Unit	N° Test			
		T1	T2	T3	T4
Solids content in slurry	% w/w	60.05	60.01	60.03	60.02
Pumping time	min	2.0	1.5	1.5	1.5
Pressing time	min	0.5	0.5	1.0	1.5
Drying time	min	4.0	4.0	4.0	4.0
Technical time	min	4.0	4.0	4.0	4.0
Cycle time	min	10.5	10.0	10.5	11.0
Moisture in cake	% w/w	16.51	16.19	16.15	16.13
Cake thickness average	mm	45.2	45.9	45.7	45.6
Dry cake weight	kg	8.47	8.36	8.36	8.56
Filtration capacity	kg D.S./m ² h	179.3	185.9	176.9	173.0

Variable	Unit	N° Test					
		T5	T6	T7	T8	T9	T10
Solids content in slurry	% w/w	60.05	60.00	60.03	60.02	60.05	60.03
Pumping time	min	1.5	1.5	1.5	1.5	1.5	1.5
Pressing time	min	0.5	0.5	0.5	0.5	0.5	0.5
Drying time	min	6.0	4.5	4.0	3.5	1.0	0.5
Technical time	min	4.0	4.0	4.0	4.0	4.0	4.0
Cycle time	min	12.0	10.5	10.0	9.5	7.0	6.5
Moisture in cake	% w/w	14.61	15.32	16.24	16.89	19.93	20.53
Cake thickness average	mm	45.7	45.6	45.9	45.7	45.3	45.6
Dry cake weight	kg	8.50	8.54	8.43	8.46	8.39	8.49
Filtration capacity	kg D.S./m ² h	157.3	180.7	187.4	197.9	266.3	290.2

7.3 Cake dropping test

The samples produced in filtration were the source material for dropping tests. The purpose of this test is to simulate the natural discharge of filter cake from the filter press, from a height of approximately 3 meters. The objective is to evaluate the mechanical behaviour and natural fragmentation of the cake before it undergoes the mixing stage with coarse aggregate.

a) Experimental Procedure

Test plan/procedure Cake behavior during discharge.

During normal filter operation the cakes are dropped by at least 3 m from the chamber to the cake conveyor under the filter, this results in the chamber sized cake breaking into smaller pieces. To simulate the drop and to prepare the cake for repulping the filtered cake should be exposed to a drop of 3m, in practice a 3m drop is impractical and 3 x 1m drops are performed. The size reduction achieved during dropping is an important parameter in defining the cake properties

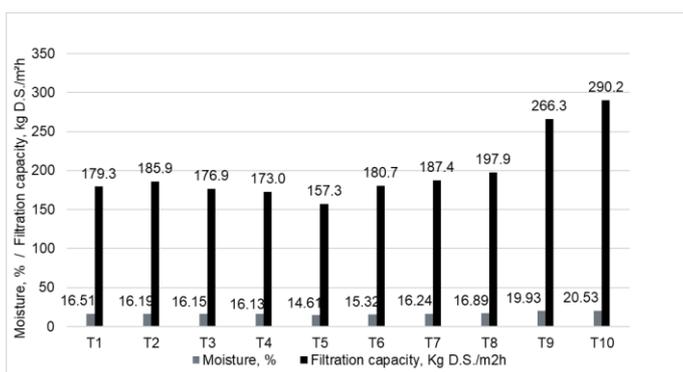


Figura 7 Comparison Filtration test results

Additional tests were conducted to determine the target moisture contents required for the filtration stage prior to performing the drop tests. These target values are based on an assumed optimal soil moisture of 17% and include the following conditions:

- 85% of the optimal moisture (14.5%)
- 90% of the optimal moisture (15.3%)
- 95% of the optimal moisture (16.2%)
- 100% of the optimal moisture (17.0%)

The moisture levels selection will serve as reference points for the subsequent drop test evaluations.

Tabla 8 Filtration test selected for cake dropping test

Variable	Unit	N° Test			
		T5	T6	T7	T8
Solids content in slurry	% w/w	60.05	60.00	60.03	60.02
Pumping time	min	1.5	1.5	1.5	1.5
Pressing time	min	0.5	0.5	0.5	0.5
Drying time	min	6.0	4.5	4.0	3.5
Technical time	min	4.0	4.0	4.0	4.0
Cycle time	min	12.0	10.5	10.0	9.5
Moisture in cake	% w/w	14.61	15.32	16.24	16.89
Cake thickness average	mm	45.7	45.6	45.9	45.7
Dry cake weight	kg	8.50	8.54	8.43	8.46
Filtration capacity	kg D.S./m ² h	157.3	180.7	187.4	197.9

- Place the cake on a 450 x 450mm board, hold 1 m above the floor and rotate the board 90 deg to drop onto a hard floor covered with plastic sheet. Photograph the cake pieces including a reference size
- recover the cake pieces, re load the board and repeat the drop. Photograph the cake pieces including a reference size
- Repeat the test a third time recovering the cake pieces, re load the board and repeat the drop. Photograph the cake pieces including a reference size. Recover the pieces and screen through 53mm, 26.4mm, 19mm and 12.5mm mesh wire screens to measure the size retained on each screen, The screening should be manual and gentle so as to not break the cake pieces further
- After finish calculate the following
 - Size distribution by sieve:

$$\% \text{ Retenido} = \left(\frac{\text{Masa retenida}}{\text{Masa total}} \right) \times 100$$

- Fragmentation Index (FI): FI is an indicator of the cake's mechanical fragility and can be correlated with moisture to understand its

structural strength under real-life discharge conditions.

$$FI = \left(\frac{\text{Masa pasante} < 12.5\text{mm}}{\text{Masa total}} \right) \times 100$$

E. Interpretation ranges

Since there is no universal standard for this index in filter cakes (unlike soils or rocks), we propose the following relative brittleness ranges:

Tabla 9 Relative fragility ranges

IF (%)	Fragilidad de la torta	Interpretación técnica
0% – 10%	Muy baja	Torta muy cohesiva, se mantiene casi entera. Difícil de mezclar.
10% – 25%	Baja	Fragmentación moderada. Aún conserva integridad. Mezcla requiere energía.
25% – 45%	Media	Comportamiento balanceado. Ideal para mezclado homogéneo.
45% – 65%	Alta	Torta se desintegra fácilmente. Mezcla eficiente pero cuidado con polvo.
>65%	Muy alta	Torta extremadamente frágil. Puede generar finos indeseables.

b) Results

The results of the cake dropping tests are summarised in the table below, the cake moistures are measured as metallurgical moisture

Tabla 10 Fragmentation analyses

Description	Unit	Value			
		T5	T6	T7	T8
% Solids Filter Cake	%	85.39	84.68	83.76	83.11
% Moisture	%	14.61	15.32	16.24	16.89
Kg of Filter Cake	Kg	9.95	10.08	10.07	10.18
Number of Drops		3	3	3	3
Weight of Particles +1°mesh (53.0 mm)	Kg	0.26	0.13	1.05	0.35
Weight of Particles +2°mesh (26.4 mm)	Kg	2.00	1.17	1.48	1.76
Weight of Particles +3°mesh (19.0 mm)	Kg	0.73	1.26	1.08	1.17
Weight of Particles +4°mesh (12.5 mm)	Kg	1.11	1.36	0.96	1.00
Weight of Particles -4°mesh (12.5 mm)	kg	5.79	6.10	5.45	5.81
Weight Final	Kg	9.89	10.03	10.01	10.08
Index (FI)	%	58.2	60.5	54.1	57.0

The selected moisture levels correspond to different fractions of the optimal compaction value (17%), with the goal of establishing the relationship between moisture content and the Fragmentation Index (FI).

This experimental design will allow us to analyze the effect of moisture on the physical integrity of the cake upon discharge and to establish the optimal filtration range from the perspective of manageability and resistance to fragmentation.

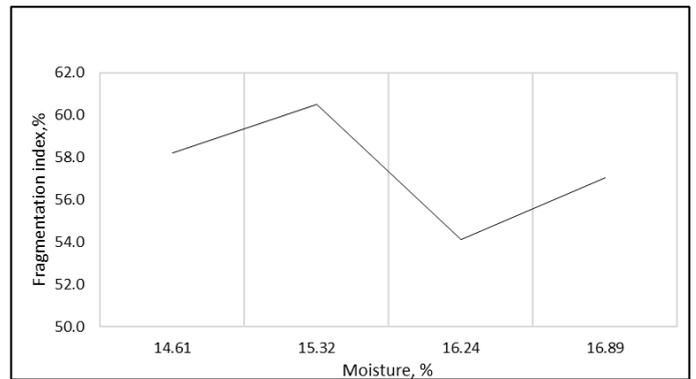


Figura 8 Fragmentation Index vs Moisture

The following figure shows the fragmentation after the first drop, second drop and third drop:



Figura 9 First drop test



Figura 10 Second drop test



Figura 11 Third drop test

7.4 Cake plasticity test

The Plastic Limit (PL) is one of the Atterberg limits used to characterize the consistency and plasticity. It is defined as the lowest moisture content at which soil remains plastic and can be rolled into threads without crumbling.

The percentage of moisture content at which the transition from solid to semi-solid state takes place is defined as the shrinkage limit (SL) to be defined as the moisture at the end of cake pressing for cake analysis.

The moisture content at the point of transition from semi-solid to plastic state is the plastic limit (PL) as determined from the plastic limit test, and from plastic to liquid state is the liquid limit (LL). Not to be measured for cake properties.

a) Experimental Procedure

- Take approximately 20 g of filter cake.
- Record the cake moisture.
- Test if the material can be formed to a cohesive ball
- Prepare several small, ellipsoidal-shaped masses of cake on a flat surface and attempt to roll into a cylinder. Reducing diameter to 3.5mm by rolling
- If the cake crumbles forming a thread approximately record the diameter at failure.
- Collect the crumbled sample, add a small amount of water, and weigh it to determine the water content. Otherwise, repeat the test with the same cake sample until a thread can be rolled

b) Results

The plotted curve of Volume vs. Moisture trend, confirms the expected trend: volume increases progressively as water content rises. Each consistency state (solid, semisolid, plastic, liquid) is clearly delineated by the critical limits measured.

Tabla 11 Atterberg limits

Description	Volume (V)	Moisture (%)
Shrinkage Limit	9.07	14.5%
Plastic Limit	9.63	16.8%
Liquid Limit	11.08	22.3%

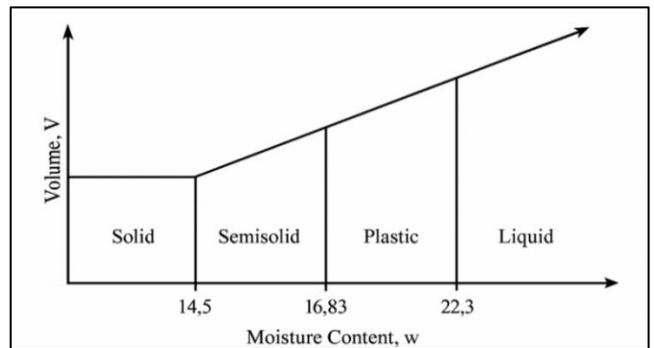


Figura 12 Volume vs. Moisture Content

The following figure shows the formation of cylindrical ellipsoidal masses.



Figura 13 formation of cylindrical ellipsoidal masses.

7.5 Bendability test

The tests aim to establish a repeatable and simple method to characterize the amount of energy and time required to blend filtered cake with waste rock.

a) Equipment

Mixing simulation equipment 70l to 100l concrete mixer



Figura 14 Concrete mixer

b) Experimental Procedure

Using the samples prepared from the filter cake properties tests add the material to a standard 70l to 100l concrete mixer with 5-10 mm crushed rock or similar. The simulation should be conducted with a ratio of 1:0, 1:1, and 1:2 tailings to waste rock substitute.

The mixer should be set at an angle of 45 deg to simulate mixing and blending
The time required to achieve a homogenous mixture should be recorded and the end mixture should be photographed

At the completion of the mixing trial the mixer contents should be discharge and the repose of the waste/tailings pile measured

Each test will use a consistent solids load weighing approximately 8 kg of total sample.

Tabla 12 Sample preparation

N° Test	Moisture %	Ratio	Filtrate Tail Kg	Waste Rock Kg	Total Mass Kg
T1	14.5	1:0	8.00	0.00	8
T2	15.3	1:0	8.00	0.00	8
T3	16.2	1:0	8.00	0.00	8
T4	17.0	1:0	8.00	0.00	8
T1	14.5	1:1	4.00	4.00	8
T2	15.3	1:1	4.00	4.00	8
T3	16.2	1:1	4.00	4.00	8
T4	17.0	1:1	4.00	4.00	8
T1	14.5	1:2	2.67	5.33	8
T2	15.3	1:2	2.67	5.33	8
T3	16.2	1:2	2.67	5.33	8
T4	17.0	1:2	2.67	5.33	8

c) Sample selection

Different mixing ratios of tailings cake to coarse aggregate will be evaluated. The aggregate used will be 4–6.3 mm crushed rock, as a representative substitute for waste rock under real-world mining conditions. As part of this study, a target moisture content equivalent to 95% of the optimum soil moisture content has been defined to maximize compaction efficiency without compromising the physical integrity of the filter cake.

The filtrate tailings sample moisture used has a moisture of 16.2% (equivalent 95% of 17% target moisture)

For each mixing level, a mixture of approximately 8 kg will be prepared per test, sufficient to complete a compaction curve with three layers.

Tabla 13 Ratio Filtrate tails: Rock

N° Test	Moisture %	Ratio	Filtrate Tail Kg	Waste Rock Kg	Total Mass Kg
T1	16.24	1:0	8.00	0.00	8
T2	16.24	1:1	4.00	4.00	8
T3	16.24	1:2	2.67	5.33	8

d) Results

The angle of repose was determined for mixtures of filtered tailings and crusher rock in different mass ratios (1:0, 1:1, 1:2). After homogenization in a rotating drum (trommel), each 8 kg mixture was discharged onto a flat surface to form a free-standing conical pile. The height and base diameter of the resulting piles were measured to estimate the repose angle.

Tabla 14 Characteristics of cone formed

N° Test	Ratio	Total Mass Kg	Time Min	Height cm	Diameter cm	Repose angle °
T1	1:0	8	2.5	13	47	29.0
T2	1:1	8	3	12	49	26.1
T3	1:2	8	4	11	52	23.0

The following figure shows the shape of the formed cone for final mixture:



Figura 15 Shape of the formed cone ratio 1:0



Figura 16 Shape of the formed cone ratio 1:1



Figura 17 Shape of the formed cone ratio 1:2

7.6 Proctor Test - Compaction for Mixture (Filtered Tailings with Crushed Rock)

To determine the compaction parameters of the filtered tailings mixture with crushed rock (maximum dry density and optimum moisture content), a Proctor-type test will be performed on the cake mixture obtained in the Metso laboratory filter. Work will be carried out at an optimum relative humidity level (95%), using a reference moisture content of 17% based on previous tests and three mixing levels.

a) Samples

For each mixing level, a mixture of approximately 8 kg will be prepared per test, sufficient to complete the full compaction curve with three layers. The total required is 24 kg.

Tabla 15 Sample requirements

N° Test	Moisture %	Ratio	Filtrate Tail Kg	Waste Rock Kg	Total Mass Kg
T1	16.24	1:0	8.00	0.00	8
T2	16.24	1:1	4.00	4.00	8
T3	16.24	1:2	2.67	5.33	8

8. Conclusions

Determination of the optimal moisture range for co-disposal

Filtration and compaction tests identified that a filter cake moisture content close to 95% of the soil's optimum moisture (approximately 16.2%) represents an appropriate operational range. This condition favors transport, discharge, and mixing with coarse aggregate without compromising the material's physical integrity or operational manageability.

Relationship between moisture content and mechanical behavior of filter cake

Drop tests from a height of 3 meters revealed a direct correlation between residual moisture and the fragmentation index (FI) of the filtered tailings. Higher moisture levels ($\geq 17\%$) increase plasticity and reduce friability, hindering effective mixing. Conversely, very low moisture levels ($< 14.5\%$) result in excessive fragmentation and loss of cohesion, negatively affecting process efficiency and blend quality.

Blend homogeneity and deposit stability

Rotary drum mixing simulations with ratios of 1:0, 1:1, and 1:2 (Tailings: aggregate) demonstrated that blend homogeneity improves significantly with controlled moisture and appropriate aggregate proportions. The 1:2 mixture achieved a lower angle of repose and more favorable particle size distribution, contributing to greater structural stability for co-disposal applications.

Methodological approach for blendability characterization

The study validated a reproducible laboratory-scale methodology to quantify the energy and time required to mix filtered tailings with coarse aggregate. This approach enables the definition of optimized filtration and mixing conditions that

enhance process efficiency while meeting geotechnical criteria set by international standards such as the Global Industry Standard on Tailings Management (GISTM).

Considerations for scaling and industrial implementation

While laboratory results are promising, pilot or full-scale validation is required. Implementing co-disposal systems demands investment in filtration, mixing, and geotechnical monitoring equipment. However, these initial costs are offset by improvements in operational safety, environmental sustainability, water efficiency, and the reduction of liabilities during mine closure.

9. References

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