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A case study on the commingling of tailings and waste rock at a Brownfields open cast mine in Ghana

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Abstract

Tailings management is multifaceted in its ultimate goal of zero harm to people and the environment, in line with the Global Industry Standard on Tailings Management (GISTM). Gold Fields is committed to conforming with the GISTM and achieving its environment, social and governance (ESG) priorities, of which one is investigating the feasibility of tailings innovation projects, such as the tailings moisture content reduction.

There is significant mining industry interest in developing geo-stable tailings storage facilities, combining tailings and mine waste to form a geochemically and physically stable landform. However, while geo-stable materials are a topic of industry-wide interest, there is a lack of a sound knowledge base and testing protocols to assess, compare and validate the performance of different technical approaches across different mineralogical and operational situations.

The paper presents the characterisation of material used to construct geo-stable tailings and waste rock management facilities and the performance of such facilities at the trial pad scale. The ultimate aim in the commingling journey at this site is to form single-footprint waste management systems with a reduced total footprint area compared to constructing separate tailings storage facilities and waste rock dumps. The material characteristics, operational environment, trial pad construction, placement and testing methods will be discussed as part of this initial step in the geo-waste journey.

Keywords: *tailings moisture content, commingling, characterisation, waste rock, trial pad*

1 Introduction

As part of its Environmental, Social and Governance (ESG) commitments and 2030 targets, Gold Fields is working towards conformance with the Global Industry Standard on Tailings Management (GISTM). The aim is to achieve this at its high-priority tailings storage facilities by August 2023 and to reduce the number of active upstream raised facilities from five to three.

In addition, Gold Fields is working towards minimising tailings volumes and water demand by actively trialling water extraction from the tailings and then commingling with the waste rock resulting in an accelerated consolidation of materials.

In support of this initiative, Gold Fields intends to conduct field trials at one of its open pit mines to study the feasibility of commingling tailings and waste rock. The study will consider different tailings and waste rock blends and different transport and placing technologies. This paper discusses the planned approach and different phases of the initial research that will be carried out during the remainder of 2023.

2 Background

The intent is to form a single-footprint waste management system with a reduced total surface area compared to the present methodology of constructing separate tailings storage facilities and waste rock dumps.

In addition, the inherent risks associated with the separate tailings storage facilities and waste rock dumps may be better managed by combining the best properties of the tailings and waste rock, i.e., commingling (Wilson et al. 2008).

This approach will provide numerous advantages, particularly on mine sites like the Tarkwa gold mine (TGM), which has a limited number of suitable sites available for future conventional storage of tailings material and the separate disposal of waste rock material. Therefore, the commingling of tailings and waste rock material is a primary consideration.

In addition, it is possible that commingling could further reduce the closure costs for the mine due to the reduced footprint and reclamation (cover) costs.

TGM, shown in Figure 1, currently generates approximately 14 million tonnes per annum (Mtpa) of tailings which are deposited in a slurry form on the current operational Tailings Storage Facility No.1 (TSF1), No.2 (TSF2) and No.5 (TSF5) at a solids concentration of between 48% to 50% (w/w). In addition, TGM generates approximately 70 Mt of waste rock per annum from the five open pits: Akontansi, Kottraverchy, Pepe, Teberebie, and Kobada.

The strip ratio for the TGM pits is currently between 6:1 and 8:1, considered adequate to investigate the commingling of the tailings and waste rock materials, as the volume of tailings produced would be sufficient to fill the voids within the waste rock.

The available ratio of waste rock to tailings will dictate the blending strategy/approach and, ultimately, the configuration of the planned field trial. In addition, TGM intends to investigate the potential of in-pit crushing as part of future mining operations.

Figure 1 Tarkwa gold mine

The commingling of waste rock and tailings can occur in many ways:

- The coarse and fine products are transported separately and allowed to mix within the disposal site after deposition (transport-deposit-mix).
- The coarse and fine products are transported separately and mixed just before or on placement at the disposal site (transport-mix-deposit).
- Co-mixing of tailings and waste rock involves thoroughly blending the two materials to a specific mix design at the plant before transportation and/or prior to the disposal site and deposition of the new material occurs (mix-transport-deposit).

For the commingling study, TGM plans to produce either high-density thickened tailings (HDTT) or filtered tailings (FT) to form the blended waste material with the mine waste rock. The HDTT and FT will be produced in batches on the mine in sufficient volumes to carry out the required trial pads.

Run-of-Mine (ROM) waste rock will be produced in the 'normal' mining process. In addition, the crushed waste rock will be produced to simulate the in-pit crushing option. Four trial pads are planned, namely:

- FT with RoM waste rock
- HDTT with RoM waste rock
- FT with crushed waste rock
- HDTT with crushed waste rock

3 Objectives

3.1 General objectives

The general objectives of commingled facilities are as follows:

- Increase the landform stability, reduce the risk of failure, and eliminate the need for dedicated surface TSFs.
- Reduce waste storage footprint through more efficient tailings and waste rock storage.
- Improve water management to reduce future environmental impacts.
- Minimise acid mine drainage (AMD) production and metals leaching from the waste rock.
- Facilitate the rapid and progressive reclamation of mine waste facilities.

3.2 Key objectives

The key objectives of the commingling project at TGM are, therefore, as follows:

- Assess feed materials' geotechnical and geochemical properties (tailings and waste rock).
- Assess the geotechnical and geochemical properties of the blended waste material based on appropriately selected mix designs, including the effects of alternative mix designs on these properties.
- Assess the practical requirements through the construction of commingling trial pads, including:
    - Material processing and handling (mixing and conveyance).
    - Construction options, comparing between constrained and unconstrained.
- Determine the geotechnical properties of the blended waste material when placed in the pads, including shear strength, water retention, hydraulic conductivity, compression, consolidation, pore pressure response, and stability.

- Gain an understanding of the geochemical properties of the blended waste material when placed in the pads, including the potential for AMD, the impact on the mine and the TSF complex's water balance, and the seepage quality and quantity.
- Assess the impact of climatic conditions at TGM on a co-mingling facility's geotechnical and geochemical properties.
- Understand the ability to utilise waste rock mixed with either HDTT or FT to form a blended waste material.
- Gain an understanding of stacking and trafficability of the blended waste material.
- Assess the viability of constructing a full-scale co-mingling facility at TGM based on the outcomes of the commingling study.
- Provide input to advance GFGL's understanding, applicability, and business case for blended waste.
- Define the key parameters that will inform future designs of co-mingling facilities at TGM in the form of a basis-of-design document.

4 Operational strategies

The operational strategy to be followed will provide for various decision points for the continued success of the study to be reviewed and confirmed. These phases will build on one another to progressively build a technically acceptable case for the full study.

The scope of work for this initial step has been divided into 4 phases, as follows:

- Phase 1 – A desktop study
- Phase 2 – Laboratory testing of the feed and blended materials
- Phase 3 – Trial pads design, construction and monitoring
- Phase 4 – Trial pads data analyses and reporting

Before a trial pad is constructed at a specific site and the ratio of tailings to waste rock blending for commingling is defined, it is crucial to understand the material constraints for the operation. Therefore, our researchers will follow the approach outlined below to evaluate, in more detail, the trial pad designs' applicability, feasibility, and ability to meet the project objectives:

- Determine the ratio of waste rock production (volumetric) to tailings production (volumetric) as a critical first step. The 'life of mine' plan typically informs this.
- Assess what proportion of the waste rock must be 'included in the waste blend by determining whether all or only a proportion pose a long-term liability (AMD, metals leaching, etc.). Notably, the proportion of waste rock in the blend will likely vary through the Life of Mine (LoM).
- Consider the particle sizes of the waste rock and assess the volume of tailings (paste, HDTT or FT) that can be consumed within the RoM waste rock or mixed in with the crushed waste rock.

5 Desktop study

The project team will conduct a desktop study to review available information and develop a design basis.

6 Material characterisation

6.1 Laboratory characterisation

Laboratory characterisation of materials is critical in developing field-scale trials of geo-stable materials (Burden 2021). While laboratory tests are limited in terms of the sample size and scale of testing compared to field-scale tests, the data from these tests help define the anticipated material performance under field-scale conditions.

6.1.1 Feed materials

Feed materials refer to the basic material groups used within a geo-stable project. The basic material groups are waste rock and tailings.

It should be noted that the particle size of waste rock can range from metres to millimetres, which makes it impractical to run laboratory-scale tests. Typically, laboratory-scale tests can only be considered on -75 mm particle sizes. However, field-scale blended tailings pads will likely be constructed using particles larger than 75 mm.

Therefore, waste rock samples will be carefully screened (using either a grizzly or vibratory screen) to estimate the percentage of particle sizes greater than 75 mm within the mixture. The research team may also consider photographic methods to estimate +75 mm particle sizes. Only materials less than 75 mm will be collected for laboratory-scale testing. The nominal sample size for laboratory testing is approximately 250 kg per geological unit.

The testing that will be carried out as part of this initial step is summarised in Table 1 below.

Table 1 Summary of material testing

Waste rock	Tailings
Physical testing	
- Particle size and hydrometer - Index testing - Specific gravity - Dry density and moisture content	
Geotechnical testing	
- Shear strength triaxial - Shear strength direct shear - Saturated hydraulic conductivity - Soil Suction & unsaturated hydraulic properties	- **Waste rock tests plus:** - Load-controlled cyclic triaxial strength - Moisture-density relationship - Consolidation
Geochemical testing	
- Elemental content and mineralogy - ARD and metal leaching (static and kinetic tests)	

6.1.2 Blended product prior to placement

The research team will conduct physical, geotechnical and geochemical testing similar to the feed materials (Table 1) on the blended materials to fully characterise them.

Laboratory-scale blending is required to generate a representative sample of geo-stable material (Burden et al. 2019). However, several factors impact the blending ratio of the final product. Firstly, the laboratory testing blending ratio will not represent a field-scale or full-scale blend due to the limitations on waste rock size that can be tested in a typical laboratory. Although laboratory-scale blended samples will not represent field-scale blends, the laboratory tests remain essential to provide indicative information on performance.

Regarding the blending ratio, it is important to recognise that the ratio of tailings to waste rock produced at an operation is not constant. Therefore, it is vital to consider the LOM waste rock and tailings production when considering blending ratios, as the tailings: rock blend will drive different outcomes for LOM solutions.

7 Field trials

7.1 Design and Construction

The trial pads (6 off) will be located on top of the northern heap leach pads (Figure 2) in an area generally representative of site conditions. They will not be disturbed or influenced by operational activities.

The trial pad base shall be fully lined with HDPE geomembrane to promote seepage collection from the trial pad and minimise infiltration to the underlying subgrade. In addition, a layer of overliner material will be placed over the HDPE geomembrane to protect it from damage and provide a drainage medium to promote seepage collection.

The trial pads will be unconstrained. In other words, they are constructed above the surrounding ground as a fill and are not laterally confined.

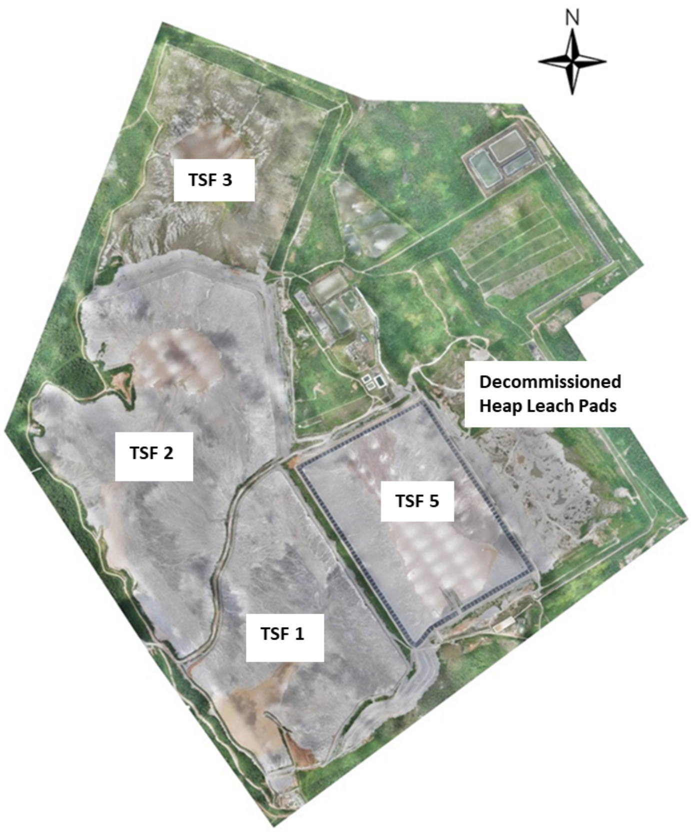

Figure 2 Tarkwa Gold Mine

Co-placement and co-mixing will involve tailings and waste rock blending prior to placement at the trial pad. Therefore, these trial pads are generally constructed by placing lifts of blended materials.

The trial pad footprint area will be large enough to avoid side slope dominance and side slope influence on the trial pad instrumentation. Engineering experience suggests that the horizontal crest width (for an unconstrained trial pad) or bottom width (for a constrained trial pad) should be at least four times the horizontal side slope distance to limit side slope effects. Figure 3 provides practical guidance for sizing trial pads, including selecting a trial pad Sizing Factor (S_f). S_f represents the relationship between the horizontal crest width and base width.

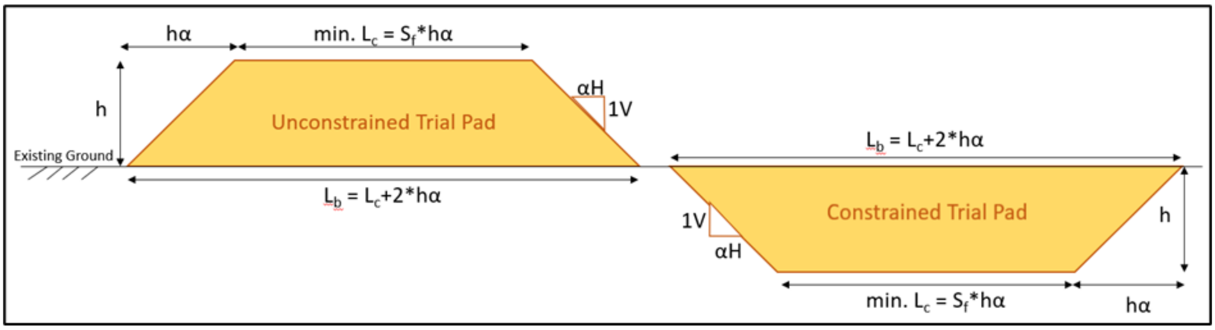

Figure 3 Trial pad geometry

For unconstrained trial pads, an ultimate pad height of 4 to 6 m is suggested. A depth of 2 to 3 m is suggested for constrained trial pads. Trial pad side slopes will be defined for worker safety during construction and operations. Typical side slopes are anticipated to be 1.5H:1V.

The trial pad lift thickness will be selected not to compromise the blended homogeneity of waste rock and tailings (e.g., segregation of materials). A lift thickness of 1 m is recommended (GeoStable 2022) for co-placement or co-mixed blending methods. For co-deposited blending methods (i.e., mixing at the trial pad following deposition), the lift thickness and blending methodology will be selected to achieve a uniform blending of waste rock and tailings. Materials will be placed in a manner expected to represent the proposed full-scale placement methods.

7.2 Monitoring

Instrumentation and data collection from a test pad are essential for monitoring the performance of the geo-stable mixture when exposed to site conditions. Numerous types of instrumentation can be used to monitor and assess various parameters of the test pad, both geotechnical and geochemical. The exact instrumentation types and monitoring regime is currently under review.

The primary purpose of instrumentation is to monitor the material's geotechnical and geochemical performance to inform the execution and performance of full-scale geo-stable structures. The secondary purpose of instrumentation is to validate geotechnical and geochemical assumptions and characteristics as determined in laboratory-scale testing. Accordingly, this requires collecting information about the geochemical and geotechnical outcomes and parameters that are material to physical and chemical controls of these outcomes.

The trafficability of the placed material is also a vital characteristic of full-scale geo-stable facilities. In this case, trafficability testing will occur either at the end of the test cycle prior to test pad deconstruction and post-test forensics or on a separately constructed test pad designed explicitly for trafficability testing.

Section 6.1.2 discusses the blended materials' characterisation before placement, while the current section focuses on the characterisation of the materials once placed.

The key outcome parameters will include the following:

- Water quality as defined by total suspended solids, chemical composition, and pH

- Water volume as defined by water release and informed by a water balance
- Geotechnical stability as defined by saturated and unsaturated shear strength
- Geotechnical slope stability and slope erosion
- Fugitive airborne dust generation from the test pad

The key control parameters will include the following:

- Phreatic surface elevation/cross-section
- Percolation rate
- Water release
- Oxygen infiltration
- Moisture content profile
- Climatic data (precipitation, temperature, wind velocity, and direction)

The following performance indicators will be reviewed upon completion of the trial:

- Uniformity of blended product
- Moisture loss and density increase
- Degree of compression and volume gain of the blended product under load
- Strength gain of blended product
- Rate of placement of the blended product to minimise shear deformations
- ARD and metal leaching potential

8 Challenges

Commingling of tailings and waste rock is not a new method, but it has only had limited use across the industry, especially where concentrator plants have high daily throughput. The base of the commingled concept combines the two core materials, tailings and waste rock, to a specified mix design ratio for deposition in a single repository. The tailings and waste rock feed materials would be transported to the trial pad location. They would be blended using a dozer and excavator to produce an engineered material with superior physical and hydraulic properties to construct post-mining landforms compared to the waste rock or tailings individually.

Research has been completed recently to formulate the mix of design theory and principles, laboratory testing, meso scale column tests and field trials. While this work has been published in theses, refereed journals and international conferences, a fledgling knowledge base remains to begin implementing this technology, especially at sites where concentrators have high daily throughput.

9 Conclusion

In summary, this is an opportunity for the industry to test a 'new' way to manage waste, adding refined approaches to an older, but not widely used, concept. There is a need to involve key stakeholders, such as communities and regulators, who must be part of this initiative in the early stages.

This study will aim to support the objective of TGM to form a single-footprint waste management system with a reduced total surface area compared to the present methodology of constructing separate tailings storage facilities and waste rock dumps.

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