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# Design Considerations for the Implementation of Tailings Based Wetcrete at Harmony's Target Mine

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## Abstract

*The Target Mine orebody is situated approximately 2400 m below surface and is accessed via a vertical shaft and decline system, totalling approximately 6000 m in length. This requires that all modes of transport be optimised. As a result of the heavy burden on the mine's logistical transport system, the mine was unable to deliver sufficient quantities of wetcrete material to the underground batching plant. This resulted in a relatively large backlog of wetcrete work building up over a number of years. The mine utilises a system of batching wetcrete underground using conventional material such as sand, cement and chemical additives.*

*Through creative thinking, a system was designed to replace the current wetcrete infrastructure with a surface batching plant where cycloned tailings are used to prepare a wetcrete mix on surface. This system promises not only to impact positively on the mine's logistical system, but also reduces the direct cost of supplying wetcrete material underground. This paper discusses the philosophy behind the design and implementation of tailings based wetcrete as well as the quality assurance requirements at Target Mine.*

## 1 Introduction

Target mine is located approximately 270 km south-west of Johannesburg in the Republic of South Africa. Geologically, the mine is situated on the eastern boundary of the Witwatersrand basin and at the northern boundary of the Free State gold fields.

The reefs being mined currently at Target are the Eldorado reefs, mainly on the western limb of a synclinal structure. These consist of single and multiple reefs that are mined by various methods, including conventional tabular stoping and massive open stoping. The thickness of individual reefs varies from 0.5 to 3.0 m. The dip of the reefs ranges from 0° to 90°. The rock formations hosting the reefs are generally very competent, with widely spaced bedding planes. The reefs are mined at depths ranging from 1800 m to 2400 m below surface.

The mine has a state of the art backfill plant, which supplies cemented backfill to the underground operation for support of the open stopes.

Access to the orebody is through a vertical shaft and then through a 6-legged decline system, totalling approximately 6000 m. All material is transported down this route in material cars using a monorail conveyance. This often creates a bottleneck situation in that not enough material can be transported down the mine to supply the underground wetcrete operation. As a result, a fairly large backlog of wetcrete work has been built up over a number of years. It was thus in the interest of mine stability that an alternative system of delivering wetcrete material had to be found.

## 2 Development support strategy

The aim of the development support strategy (Ras and Basson, 2002) at the mine is the following:

- Prevent local rockfalls.
- Reduce rockburst damage.
- Permit the tunnel or excavation to be used for its desired function, for its desired life, without interruption.

- Be cost effective.

Hence the mine follows a strategy that requires all long-term tunnels to be supported with wetcrete to a total average thickness of 40 mm.

The current wetcrete operation consists of a surface screening plant where the wetcrete aggregate (graded river sand) is screened before it is sent underground to an underground batching plant where cement and chemical additives are mixed together. The batching plant is situated approximately midway down the decline system, resulting in long transport distances of batched wetcrete material to the working areas of the mine.

A total of approximately 108 $m^3$ of wetcrete material was required to meet the monthly demand. This equates to 270 materials cars per month (± ten cars per day). The availability of classified tailings and a complete system of backfill ranges (backfill pipe system) to the underground operation provided an ideal opportunity to investigate a system of tailings based wetcrete. The aim of this investigation was to find an alternative wetcrete mix design that was possible to prepare on surface and that could be pumped to the working area through existing ranges. Similar technology is well known to the South African platinum mining industry (Van Vuuren, 2007) where cementitious slurry is pumped down mines to construct concrete packs.

A project task team consisting of senior production personnel, backfill plant operators and rock mechanics engineers listed the following approach to the investigation. The project would eventually follow a two-tiered approach. While thorough research is done on pumping technology for a high density cementitious material, cycloned tailings will pumped into a holding tank at the current batching plant to allow implementation of the tailings based wetcrete system.

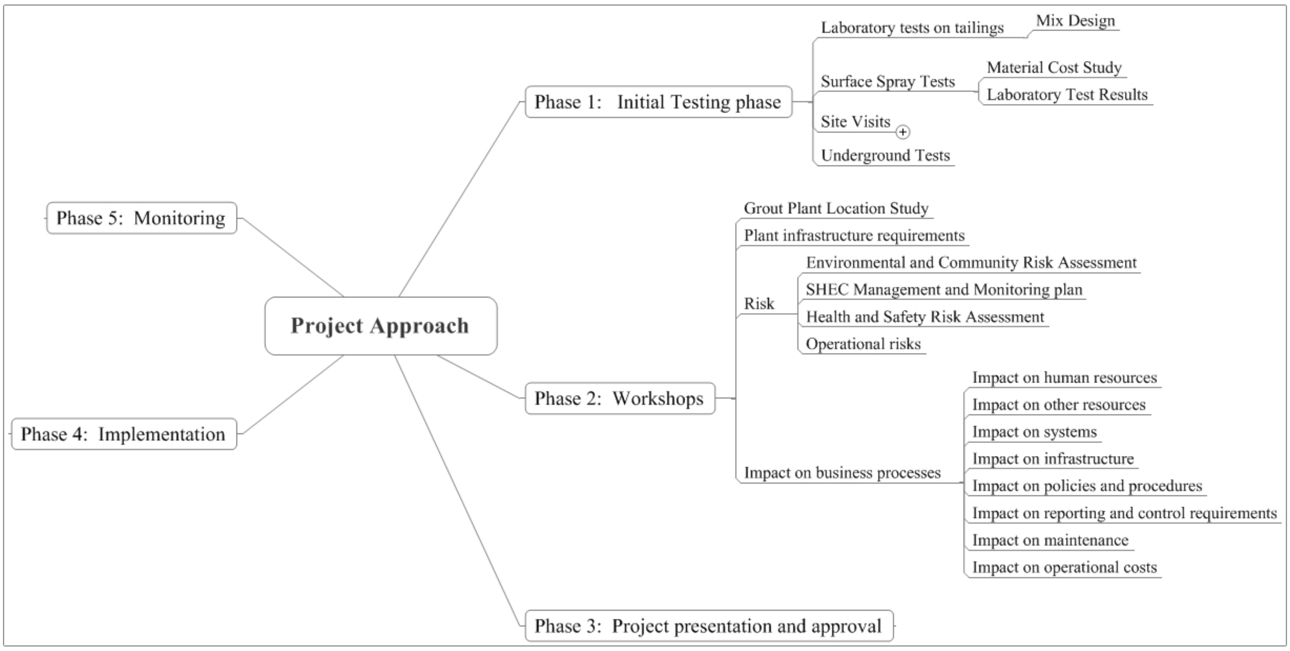


**Figure 1 Project approach layout (Target mine, internal documentation)**

## 2.1 Initial testing

The most important aspect of this project was to provide proof that tailings could actually be used as an alternative to river sand as aggregate material. In consultation with Chryso Southern Africa, a program was established where tailings samples were tested at a laboratory to determine a mix design for the testing phase. Results from these tests were promising and Table 1 shows the mix designs proposed for further testing.

**Table 1 Different mix designs used for laboratory testing (Barker, 2006)**

| DESCRIPTION | SG | MIX A | | MIX B | | MIX C | |
|---|---|---|---|---|---|---|---|
| | | **Volume (l)** | **Mass (kg)** | **Volume (l)** | **Mass (kg)** | **Volume (l)** | **Mass (kg)** |
| Cem 1 42.5 Powercrete | 3.14 | 159 | 500 | 159 | 500 | 64 | 200 |
| Pozzfill | 2.2 | 136 | 300 | 136 | 300 | 45 | 100 |
| CSF | 2.2 | 14 | 30 | 0 | | 0 | |
| Superpozz | 2.2 | 0 | | 14 | 30 | 18 | 40 |
| Tailings | 2.7 | 289 | 780 | 289 | 780 | 0 | |
| Wet Tailings | 1.7 | | 0 | | | 9 | 14.6 |
| Water | 1 | 415 | 415 | 380 | 380 | 40 | 40 |
| CHRYSO OPTIMA 206 | 1 | 5 | 5 | 8 | 8 | 8 | 8 |
| CHRYSOTARD CE | 1 | 5 | 5 | 5 | 5 | 6 | 6.4 |
| Total | | 1023 | 2035 | 991 | 2003 | 190 | 409 |
| SG Actual | | | 1.94 | | 1.88 | | 2.1 |
| **Strength Tests** | | **SG** | **UCS (MPa)** | **SG** | **UCS (MPa)** | **SG** | **UCS (MPa)** |
| 7 Day | Sample 1 | 1.99 | 21.6 | 2.09 | 26.1 | 1.96 | 18.7 |
| | Sample 2 | 1.99 | 21.9 | 2.08 | 27.3 | 1.98 | 16.5 |

Surface spray tests were conducted to prove that the proposed mix design provides a practical alternative wetcrete that can be sprayed with conventional wetcrete machinery. Different types of fibre was used to determine the optimum composition that would achieve strengths and energy absorption as required by the mine’s wetcrete strategy. The results energy absorption capacity tests of sprayed panels are shown in Table 2.

**Table 2 Different fibre mix designs used for underground testing using mix C (Barker, 2006)**

| Fibre type | Age when tested | Corrected Energy Absorption value (Joules) | |
|---|---|---|---|
| Standard Oxy Fibre | 28 days | 617 J | 790 J (Ave) |
| | | 919 J | |
| | | 834 J | |
| Chryso S/50 Fibre | 28 days | 474 J | 544 J (Ave) |
| | | 614 J | |
| New Oxy Fibre ( Prelim ) | 28 days | 896 J | 774 J (Ave) |
| | | 652 J | |
| Metalloy test fibre | 28 days | 373 J | 373 J |
| Bonbex + Target Fibre | 28 days | 534 J | 534 J |

### 2.2 Underground testing

Based on results of the above laboratory tests, a decision was made to test and prove the mix design underground using the mine's own wetcrete machinery and batching plant. Using mix design C with the standard Oxy fibre as shown in Table 2 actual underground tests were done. Underground tests proved to be successful and results are shown in Table 3.

**Table 3 Underground test results for mix C with standard Oxy fibres**

| Site ID | Age when tested (Days) | UCS (MPa) |
|---|---|---|
| 1 | 54+ | 39 |
| 2 | 28 | 34.3 |
| 3 | 28 | 27.3 |
| 4 | 54+ | 45.2 |
| 5 | 54+ | 44.5 |
| 6 | 54+ | 43.7 |
| 7 | 54+ | 40.6 |
| 8 | 14 | 17.2 |
| 9 | 28 | 35.9 |
| 10 | 54+ | 54.6 |
| **Average** | | **38 MPa** |

As part of quality control and ensuring that the applied product is to design specifications of 30 MPa on the rock walls, regular core tests and cube tests were done. It became apparent in the early stages of the project that the number of additives that were added in the laboratory testing would have to be reduced due to the logistical restriction of the shaft.

It was found that the average uniaxial compressive strength of the wetcrete on the rock walls is 38 MPa, which exceeds the design criteria and can still be reduced for further cost savings for mix design C.

### 2.3 Impact on business processes

- The new system allows better utilisation of the wetcrete workforce due to improved product availability.
- Higher availability of Monorail system for other processes critical to the production process.
- Reduction in waste of raw materials in the process of transportation and storage underground.
- Unit cost of wetcrete was significantly decreased. A 25% saving in the direct cost of wetcrete is realised. Considering the total cost of the wetcrete operation, including factors such as logistics and workforce utilisation, the monthly saving is as much as 60%.
- Reduced environmental impact, as more tailings material is pumped back underground instead of to storage facilities on surface. Less reliance on natural resources such as river sand.

## 3 Material specifications

Using the Q System to evaluate the rock mass on Target mine the shotcrete requirements for tunnel widths 4 m and 6 m wide could be determined. The Q System classification is based on three important aspects:

- Rock block size (RQD / Jn).
- Joint shear strength (Jr / Ja).

- Confining stress (Jw / SRF).

Where: *RQD* is the rock quality designation.

$J_n$ is the joint set number.

$J_r$ is the joint roughness number.

$J_a$ is the joint alteration number.

$J_w$ is the joint water reduction factor.

*SRF* is the stress reduction factor.

$$Q = \frac{RQD}{J_n} x \frac{J_r}{J_a} x \frac{J_w}{SRF} \quad (1)$$

$$= \frac{75}{9} x \frac{1.5}{2} x \frac{1}{50}$$

$$= 0.13$$

Figure 2 below is a modified graph for mining excavations in which the excavation stability ratio (ESR) is incorporated (Stacey, 2001). From the chart below the required thickness could be determined. It was found that for a tunnel with a 4 m wide span the minimum shotcrete thickness is 40 mm and for a 6 m wide tunnel span a 50 mm shotcrete thickness is recommended

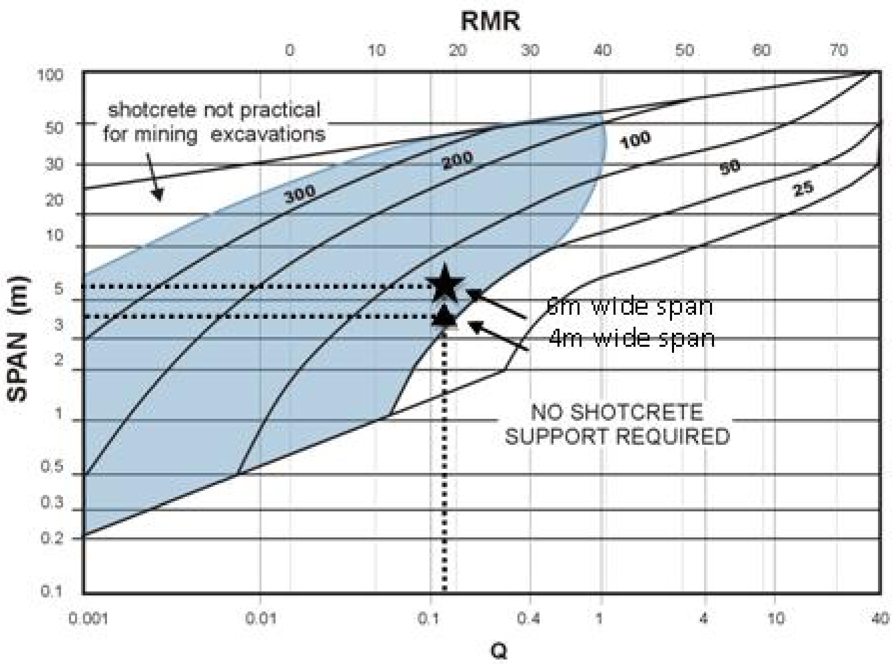


**Figure 2 Shotcrete support design chart (Stacey, 2001)**

The actual quantity of wetcrete that can be applied per day with the new tailings system using four Trans-mixers and one Spray-mac for an applied 40 mm thickness is 346 $m^2$/shift. For a 50 mm thickness 277 $m^2$/shift can be achieved assuming that no breakdown of equipment occurs. This equates to 25 linear metres per shift for a 5 x 4.5 m tunnel and 17 linear metres for a 5 x 6 m tunnel.

This is significantly more than with the old wetcrete system. Due to the high quantities of wetcrete required this system can be utilised more cost effectively.

### 3.1 Aggregate

The maximum allowable SG for the classified tailings is 1.75 at the surface Pachuca before being sent underground. If the SG is higher than this, pipe wear becomes high and the possibility of pipe blockages increases. Once underground 280 litres of tailings are required to prepare a wetcrete batch to fill a Trans-mixer vehicle (capacity of 0.38 $m^3$).

### 3.2 Strength

For shotcrete an in-situ uniaxial compressive strength of 30 MPa at 28 days are required.

### 3.3 Thickness

The minimum average shotcrete thickness required for a 4m wide tunnel is 40 mm and for a 6 m wide tunnel is 50 mm.

### 3.4 Fibre Content

The good performance of the Chryso Shotcrete Oxyfibres with the tailings wetcrete mix is due to the bond that it has with the cement paste. The Chryso Shotcrete Oxyfibres have been treated with a Crypsinated surface to give excellent wetting and bonding properties. The other fibres either rely on the aggregates to fibrillate the ends of the fibre for bonding or, as they are just sheet polypropylene, the cement particles have no grip or bond.

For the classified tailings wetcrete a ratio of 3 kg fibres per 0.38 $m^3$ batch wetcrete is specified.

### 3.5 Additives

Additives are added at the batching plant in accordance with the ratios specified below.

The following quantities of additives are normally used:

| | |
|---|---|
| Cement | 180 kg / 0.38 $m^3$. |
| Condensed Silica Fumes | 50 kg / 0.38 $m^3$. |
| Plasticiser | 3.0 litres / 0.38 $m^3$. |
| Retardant | 3.0 litres / 0.38 $m^3$. |

Accelerator is added at the nozzle at a rate of 1.0 litre / minute.

## 4 Quality assurance

### 4.1 Aggregate

The SG of the classified tailings are monitored and maintained at 1.75 at the surface backfill plant, through hourly sampling and testing by the batch plant operator.

### 4.2 Sump tests

Regular slump tests (using a DIN flow table) are performed as to ensure that the correct viscosity of the wetcrete is maintained. The ideal spread for slump tests is the order of 400 mm.

All these records are kept by the batch plant operator for all test results. These test results are recorded on a control sheet, of which a copy is supplied to the Rock Engineering department on a monthly basis. This control sheet shows the date on which the test was done, the mean flow of the test specimen and the area where the wetcrete was used.

### 4.3 Wetcrete cube tests

The strength is monitored from cast cubes and is tested in the Rock Engineering Laboratory.

For each wetcrete batch one 100 x 100 mm wetcrete cube must be cast. These cube tests are done as an additional control to ensure the correct final strength is obtained.

The minimum uniaxial compressive strength for the wetcrete cubes should be 45 MPa after 28 days as to ensure an in-situ strength of 30 MPa on the rock walls. This relationship has been determined empirically at Target Mine using quality control data accumulated over several years.

**Figure 3 Cube tester**

## 4.4 Thickness control

As to monitor and control the thickness of the wetcrete a thickness control punch with a protruding pin as long as the specified thickness, must be used to punch the wetcrete layer at least once every 1 $m^2$. The wetcrete must be applied until the disk on the punch makes a ± 2 mm deep impression in the wetcrete.

## 4.5 In-Situ core tests

The strength is monitored from cast cubes and cores drilled from the wetcrete walls and tested in the Rock Engineering Laboratory. Every ten linear metres, a block of 500 x 500 x 100 mm thick is sprayed on the sidewall at grade elevation as shown in Figure 4. Two cores samples are taken from these panels and tested to confirm the Uniaxial Compressive Strength of at least 30 MPa.

**Figure 4 Photo showing the cores drilled out of the sidewall at grade elevation**

### 4.6 Tensile and bond strength test

Using a DPG100 tester from Hilti the tensile strength and bond strength to bare rock of the shotcrete is tested as shown in Figure 5.

**Figure 5 DPG100 tester from Hilti, testing the bond strength**

### 4.7 Energy absorption capacity plate test

This is mainly done to fine tune the design of the tailings wetcrete and is not done on regular intervals. The energy absorption required is 700J.

## 5 Future work

This project changed the way in which wetcrete is being viewed. In future even more cost savings can be achieved if the SG of the product being pumped from surface to underground can be increased. If this can be achieved the product that is required to be applied to the rock wall, can actually be mixed on surface. Research should be done on new ways of pumping tailings wetcrete with a SG of >2 from surface to the underground batch plant.

## 6 Conclusions

In the modern competitive mining environment, the challenge will always be for engineers to provide creative and innovative ways of solving engineering problems. Tailings wetcrete provides an opportunity to not only solve logistical problems at Target Mine, but also to increase the amount of wetcrete sprayed per month in order to eliminate backlog and reduce the risk profile at the mine.

It was found that the average uniaxial compressive strength of the wetcrete on the rock walls is 38 MPa, which exceeds the design criteria. Thus there is still some design work to be done in reducing the strength to 30 MPa for further cost savings.

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## References

Barker, M. (2006) Chryso Chemicals, personal communication, consultancy reports.
Ras, D.J. and Basson, F.R.P. (2002) Brief overview of the geotechnical aspects at Target Mine, Internal presentation.
Stacey, T.R. (2001) Best practice rock engineering, handbook for "other" mines, SRK Consultancy, pp. 12-141.
Van Vuuren, F. (2006) Electro Hydro World (grout plant specialists), personal communication.