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Use of Paste Fill on Cycle at Turmalina Mine

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ABSTRACT

Turmalina Mine has been unsuccessful on mining a high-grade thick zone of its orebody using a sublevel stoping bottom-up sequence with rock fill by having high dilution and ore losses. Being one of few mines in Brazil with a paste fill plant, Turmalina Mine – that used to paste fill only open stopes in old areas – saw as an alternative using paste fill on a primary and secondary stoping sequence to reduce probability of ground falls and successfully extract ore from the high-grade thick zone without leaving rib pillars, increasing recovery

Empirical formulas and Map3D – boundary element numerical method - were used to define needed plug and mass fill strengths to reduce risk of liquefaction, to use paste filled areas as working platforms and for vertical exposure after secondary mining with low dilution.

A binder created for Turmalina tailings considering its rheological characteristics to achieve good flowability and sufficient compressive strength made possible to reach an optimal cycle, combining low binder utilization and sufficient compressive strength for each step of the cycle confirmed by uniaxial compression tests done in specimens with different binder content and ages.

Filling consists of a 5% plug fill and then a 3% mass fill after a two days wait for the plug fill to reach 100kPa. Filled stope is ready to serve as a working platform after 3 days, when it reaches 170kPa. Secondary stoping is sequenced after 28 days when mass fill finishes, as it is ready to have a vertical exposure with a strength of over 500kPa. Paste fill specimens collected are tested to confirm the strengths needed before each step.

By implementing paste fill in the sublevel stoping sequence, the mine is planning to control operational dilution at a maximum of 15% and increase ore recovery to 95% in the high-grade thick zone.

INTRODUCTION

Turmalina Mine is an underground gold mine operated by Jaguar Mining Inc., a Canadian junior gold company and it is located in Conceição do Pará, a city near to Belo Horizonte, Minas Gerais state, in the Iron Quadrangle Region - a greenstone belt. Jaguar operates Turmalina Mine since 2006, using longhole stoping in a bottom-up sequence with delayed backfill.

A few methods were tried out to mine Turmalina's high-grade thick zone. Primary and secondary transversal stoping were done, but there was a considerable amount of ore left behind due to rib pillars. On the last panel, mining was carried out in a retreat sequence until consecutive ground falls happened on the stope hangingwall and back, what made impractical to continue mining and left over 3000oz behind.

Turmalina is one of the few mines in Brazil to have a paste fill plant but it was underused, with the intention to fill old areas with no activities and with geotechnical issues. The necessity of having more control of its mining made the Turmalina's Technical Services team work on several possibilities of sequencing that could combine less development meters, a controlled hydraulic radius, a safe sequence, low dilution and high recovery. The use of paste fill in mine sequence is an opportunity to optimize control of the operation, granting a better ore recover of the areas.

METHODOLOGY

Turmalina's pipeline consists of HDPE pipes with 6" of internal diameter. The paste is pumped from the plant to a vertical borehole and after that, transportation of paste fill to wanted stope is done by gravity, going down a pipeline of over 6km following the mine's decline. The pipeline material was taken into consideration when creating the ideal binder for the mine. Paste needed to have a good flowability and a delayed initial setting in case there was any problem with the long pipeline during pumping.

Before making a mining sequence plan for Turmalina's orebody thick zone, a series of uniaxial compression tests were carried out after 3, 7, 14 and 28 curing days, using different binder contents and approximately 68% solids content. According to literature, a strength limit of 100 kPa is admitted to avoid liquefaction (Hassani and Bois, 1992) and, according to Craig (1990), a bearing capacity of 30 kN for working platform. The bearing capacity of paste fill can be calculated using Terzhaghi's expression modified by Craig (1995):

$$Q_f = 0.4\gamma B N_\gamma + 1.2 c N_c \tag{1}$$

N_γ and N_c (bearing factors) were developed by Hansen (1968):

$$N_\gamma = 1.8(N_q - 1)tan\emptyset \tag{2}$$

$$N_c = \frac{(N_q - 1)}{tan\emptyset} \tag{3}$$

$$N_q = tan^2\left(45^0 + \frac{\emptyset}{2}\right)\exp\left(\pi tan\emptyset\right) \tag{4}$$

According to Hassani and Bois (1992), B corresponds to the tire contact width and can be determined by the following relationship (see Figure 1):

$$B = \sqrt{\frac{F_t}{p}} \tag{5}$$

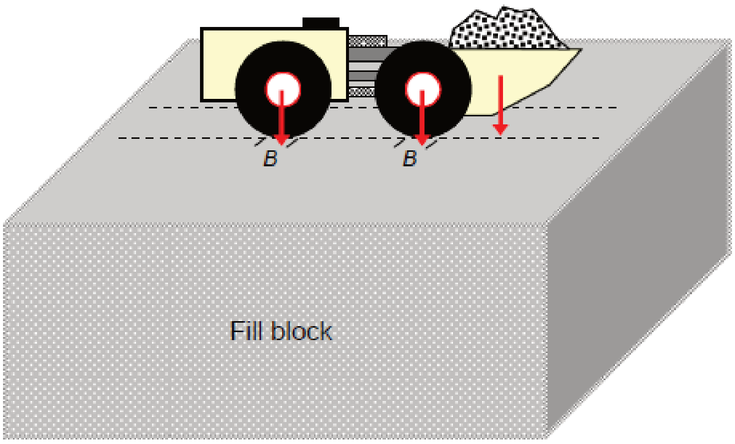

Figure 1 Schematic of working platform (HASSANI & BOIS, 1992 *apud* BELEM & BENZAAZOUA, 2008).

After secondary stoping, fill placed in the primary stope needs to have enough strength to remain stable after adjacent blasting. Assessment of needed strength is done using Mitchell analysis (1992), based on wedge limit equilibrium, neglecting any strength resulted from friction considering the long term. Mitchell (1983) proposed a formula based on centrifugal modelling to assess the stability of a freestanding backfill:

$$UCS = \left(\frac{\gamma H}{1+\frac{H}{L}}\right) FS \tag{6}$$

The bearing capacity and UCS were then calculated based on the equations listed above and alongside with laboratory results guided Turmalina's proposed sequencing.

RESULTS AND DISCUSSION

Laboratory tests results and proposed sequence were inputs for the numerical model on Map3D (see Figure 2). Stress and strain analyses, as well as probability of failure, were done in order to evaluate the sequence; it needed to be good enough to guarantee stability and avoid dilution greater than 15%.

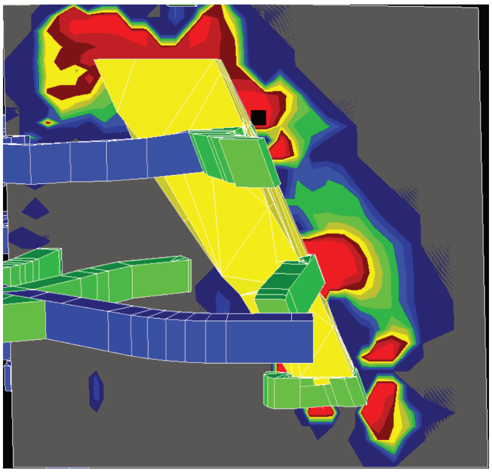

Figure 2 Probability of failure of the stopes after complete mining and filling.

Calculations shows that after 3 days, bearing capacity of paste fill – considering a LHD with a full bucket, which is the heaviest equipment that will work on top of paste fill – is over a 100kN.

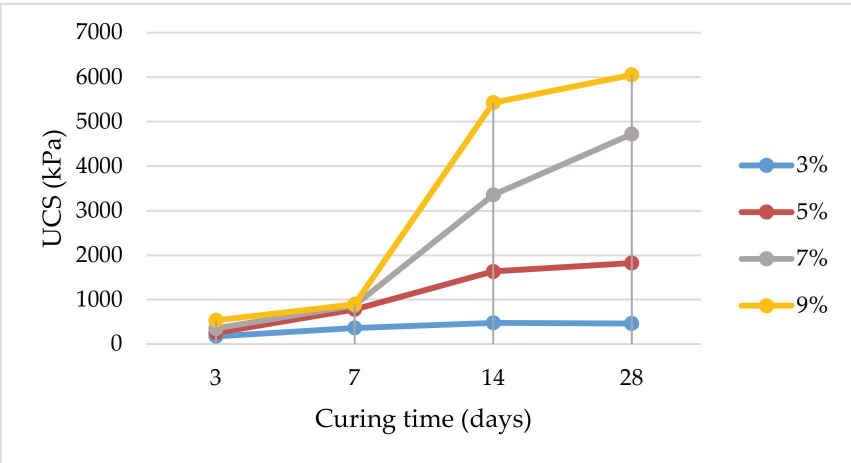

Chart 1 Strength for different binder content and curing times.

The design UCS calculated for vertical exposure considering planned stopes for Turmalina, which has approximately 20m length by 20m height using 1.5 as factor of safety, is 270 kPa.

Having the calculated needed strength and the laboratory results of UCS tests (Chart 1), it was decided to use 5% of binder on the plug fill as it reaches higher strengths faster to reduce pressure on the bulkhead. For the mass fill, it was decided to use 3% of binder and only blast secondary stopes after at least 28 days, in order to have a higher factor of safety.

Turmalina's plant can pump approximately 50 cubic meters per hour. The first stope to be filled in the defined sequence has nearly 3800 cubic meters. Then, filling the stope with paste fill will take seven days, considering the three days wait between plug and mass fill. After filling, the stope will be ready to be used as a working platform after three more days. Comparing with the mine's capacity of rock filling, it would take over 15 days to complete it.

The mine did a trial run filling an open stope with paste to verify the pipeline and the Schwing plant integrity. The test only used 5% of binder and uniaxial compressive strength test were only performed after 3, 7 and 28 days (see Chart 2). The strengths were lower than those found on laboratory tests but still sufficient to attend initial sequence planned for mining the thick-zone.

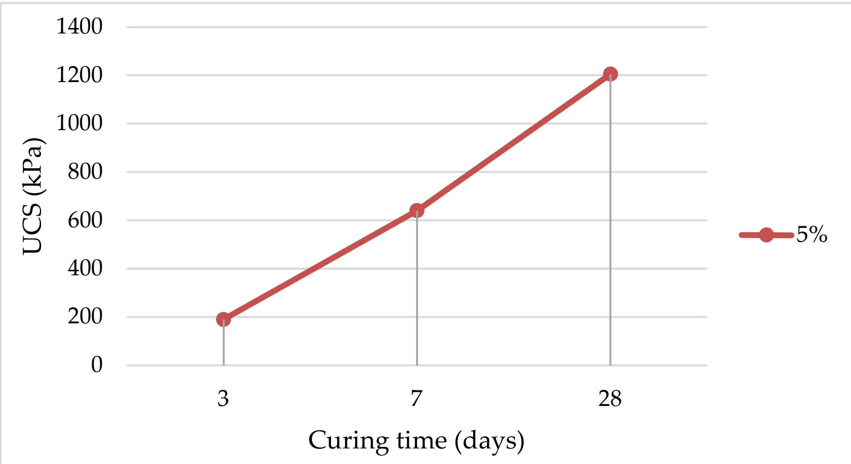

Chart 2 Strengths for 5% binder content paste fill produced on trial run.

With the information in hand, the stoping sequence was decided. Filling each stope consists in first pouring plug fill with 5% of binder until it reaches up to 1m above the stope brow. Pouring of mass fill will only be done after a 3-days wait for the plug fill to reach 170 kPa and reduce pressure on the bulkhead. Then, the mass fill with 3% of binder will follow (see Figure 3). The bulkhead that will be used is a concrete block wall, but in the future, the mine will use a rock pile.

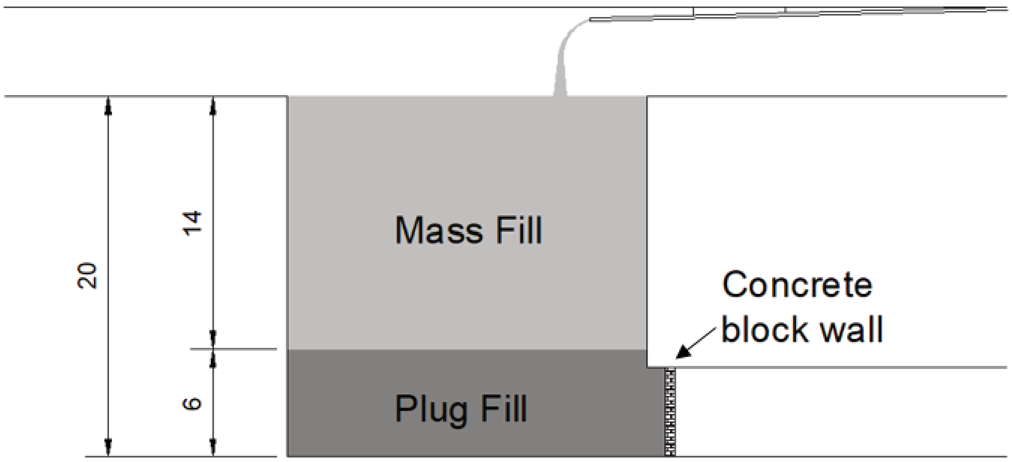

Figure 3 Filling schematics of a stope.

The defined sequence is a bottom-up mining, where the thick zone level will be full developed before the operation on the stopes. Mining all thick zone in such way could be possible to keep stability, to maximize extraction and to reduce cycle time consisted of mining the three central stopes, which would be filled with paste at the end. Only after mining these three stopes, the secondary stopes could be mined, as it can be seen on Figure 4. The hydraulic radius chosen for each stope allow the hangingwall to be stable long enough to complete filling with paste. The choice of stope span was based on Mathew's Stability Graph Method and on a numerical model with Map3D. Apart from a 5m sill pillar left between levels, the rest of the thick zone will be mined, which means a 95% recovery.

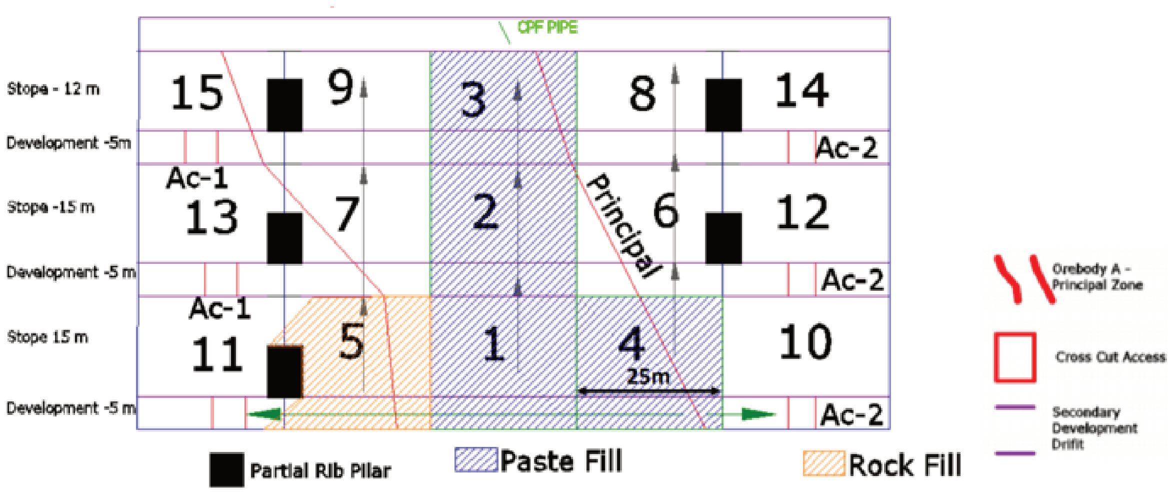

Figure 4 Sequence planned for the panel.

As filling of the bottom stope happens, second stope on the sequence can be prepared for mining from the upper level. Drilling the stope will take approximately two weeks, giving the paste-filled stope 7 days to cure after complete filling (see Figure 5).

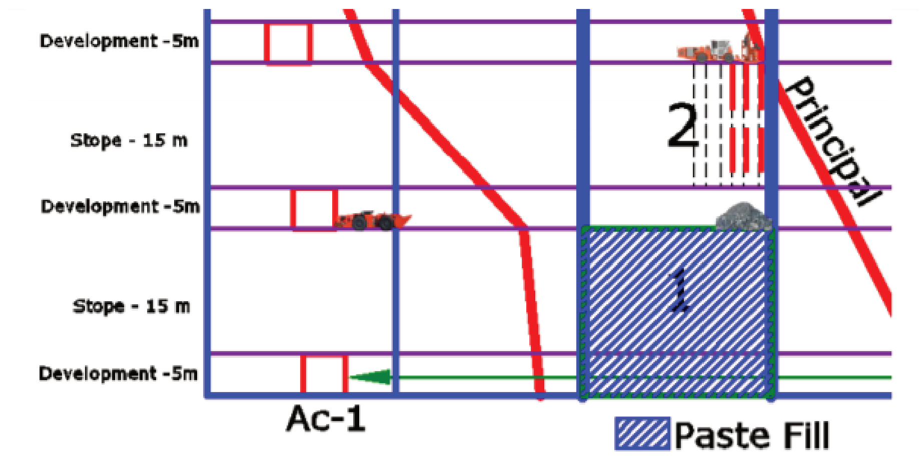

Figure 5 Preparation of second stope to be mined.

CONCLUSION

The use of paste fill in mining sequence will allow Turmalina to have complete control of mining its high-grade thick zone, reaching a 95% recovery, as there is no need to leave rib pillars. A sill pillar is being left between panels, but in the future Turmalina can choose to use paste fill as a sill mat and eliminate the necessity of it. Dilution will be kept to a limit of 15% by keeping the unsupported hangingwall to a controlled hydraulic radius and doing paste filling as soon as mucking in completed.

The binder used, with a special recipe for Turmalina's tailings, is gentle on the HPDE pipeline but maintains its capability of reaching high strengths in less days than it would using only Portland cement as a binder and making possible to mine the sequence in 2/3 of the time needed if using rockfill.

The analysis of the areas with numerical models and the laboratory tests of paste fill produced will be a routine for the Technical Service team that will periodically update the data to optimize the operation.

ACKNOWLEDGEMENTS

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NOMENCLATURE

γ bulk unit weight of the fill (kN/m³)

c fill cohesive strength (kPa)

B width of square footing at surface contact position (m)

N_y unit weight bearing capacity factor

N_c cohesion bearing capacity factor

N_q surcharge bearing capacity factor

∅ angle of internal friction of fill

F_t tire loading force (kN)

p tire air pressure (kN/m²)

γ fill bulk unit weight (kN/m³)

H fill height (m)

L stope strike lenght (m)

FS factor of safety

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