Paste 2018 – RJ Jewell and AB Fourie (eds)

doi:10.36487/ACG_rep/1805_25_Eriksson

Garpenberg mine – 10 years of mining with paste backfill

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Abstract

In 2007, Garpenberg mine started Boliden Mines' first paste backfill operation. From 200,000 t in 2007, the annual paste backfill produced reached 1,000,000 t in 2016. Over the years, several changes have been made in the paste fill plant and the reticulation system to meet the increasing demand on paste backfill. Committed employees with a high degree of freedom to make suggestions and implement improvements have achieved this. Ten years after start-up, or 6 M t of paste backfill later, this paper discusses the present operation and the major changes that have occurred over the years to optimise both the operation and the paste fill quality.

Keywords: *backfill, operation*

1 Introduction

This paper presents how paste backfill used in the Garpenberg mine has developed from being a new backfilling method for the Boliden Mines to being a proven and cost-effective method today. Committed employees with a high degree of freedom to make suggestions and implement constant improvements in the use of this new technology are the reason behind our achievements.

The Garpenberg mine is owned by the Boliden Group and is located 180 km northwest of Stockholm, the capital of Sweden (Figures 1 and 2). In the late 90s, the Lappberget orebody was discovered from near field exploration in the mine. The orebody is dipping 85 degrees, starts at 400 m depth and the limit at depth is unknown. It is 250 m long and its width varies between 20 to +100 m. Exploration of the orebody started at 900 m depth with cut and fill mining leaving pillars surrounded by waste rock, but was shifted to transverse sublevel open stoping with paste backfilling when the paste fill plant commenced operation in 2007. Today, mining is ongoing between 500 and 1,250 m.

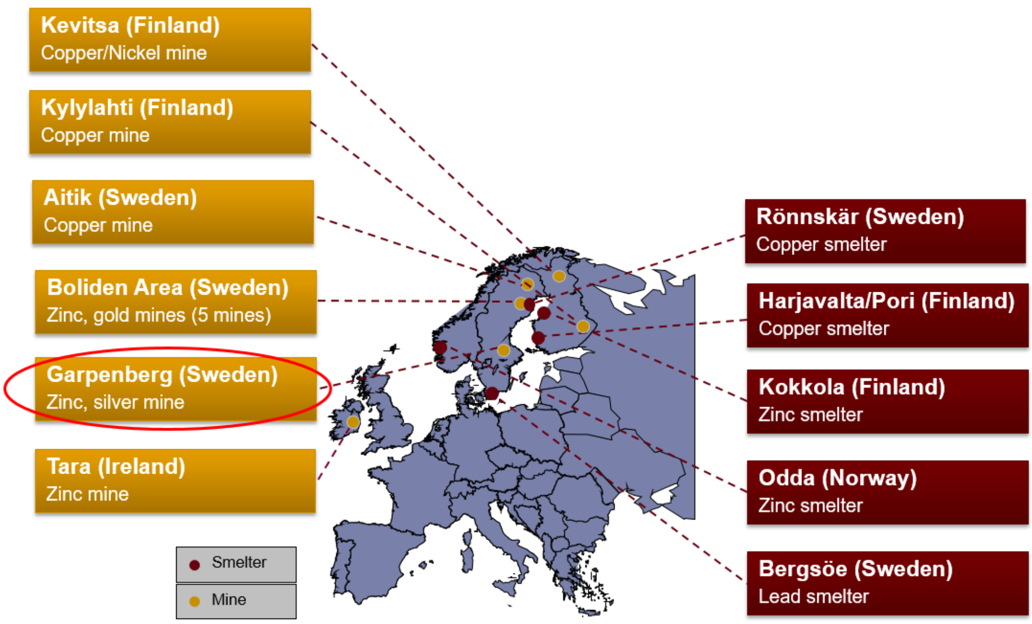

Figure 1 The Boliden Group mines and smelters

Figure 2 The Garpenberg mine – arrow pointing at the paste fill plant

The stopes are mined both overhand and underhand in a primary–secondary mining sequence where the primary stopes are backfilled with paste and the secondary stopes are usually backfilled with waste rock. The primary stopes are mined at least one level ahead of the secondary stopes to limit back span. Mining is ongoing on four 150 or 200 m high levels creating sill pillars between the levels. To mine the sill pillars, drifts are developed in the paste backfilled stopes above the sill pillars. Drifts in paste backfill also occur in underhand open stoping areas.

2 Strength demand

The open stoping mining method puts different demands on the paste backfill strength governed by four different loading conditions on the backfill. The lowest demand is the risk of liquefaction of the paste backfill due to vibrations from blasting or mining-induced seismicity. Secondly, the strength of the paste backfill in the primary stopes will have to withstand the load of its own weight when secondary stopes are mined which expose the paste backfill. Thirdly, the most common demand of the mine is that paste backfill in the primary stopes will give support for adjacent secondary ore pillars above the back of open secondary stopes. This demand is calculated as the shear resistance from the paste backfill on the ore pillar. The last and highest demand is when developing drifts in the paste backfill. This occurs when mining a sill pillar and when underhand open stoping is used. In these cases, the paste backfill will be exposed in the back of the open stope.

Numerical analysis for different geometrical situations have been studied to evaluate the strength demand for mining below a paste backfilled stope. Furthermore, the strength of the paste backfill is reduced by a waste rock bed that can be 0–2 m thick and is mucked into the stope when the paste backfill is partly cured and is strong enough for transporting the waste rock into the stope with load–haul–dump units. The waste rock bed is used to give a solid floor for mucking the stope above. This waste rock bed gives a weakness plane in the paste backfill, which induces shear forces in the paste backfill and creates vertical tension cracks parallel to the exposed paste backfill walls (Figure 3). This type of phenomena has also been observed as paste backfill dilution in some stopes.

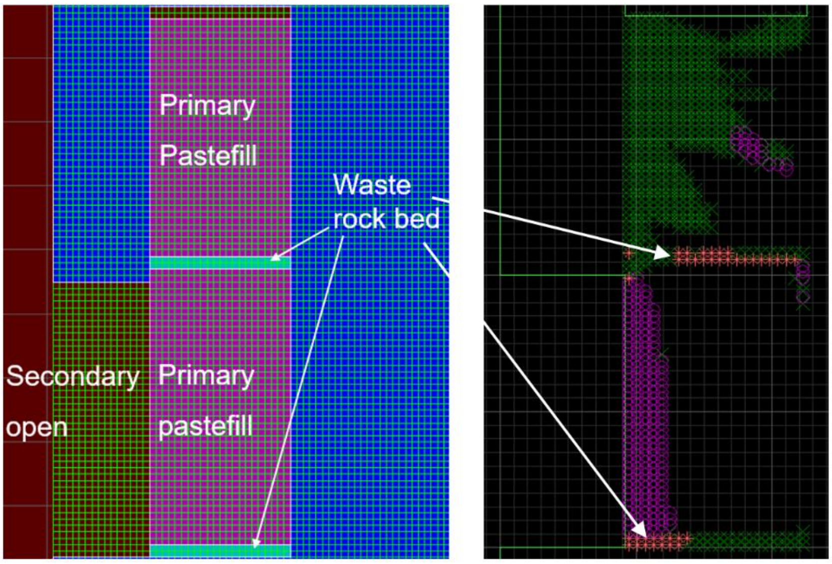

Figure 3 Model studies showing the waste rock bed inducing risk for vertical slabs when the paste backfill is exposed in the secondary stope

3 Recipe

The paste fill plant was originally constructed with three silos for binder storage. This made it possible to blend different binders into the paste mix. The advantage of using ground granulated blast furnace slag (GGBS) to achieve a cost-effective paste backfill and to reduce the risk for strength decrease due to internal sulphate attack led to the decision to evaluate different recipes for paste backfill in the laboratory. In Sweden, GGBS was only commercially available from one supplier. However, the grinding of the GGBS was not far from the mine, hence transportation costs were relatively low. Different slags from producers in Europe were tested and even though the slag from the Swedish supplier was far from the most efficient, it was chosen due to logistical constraints from other suppliers. Compared to Byggcement (Swedish Portland cement CEM II/A-LL 42.5 R) only, an 80/20 slag/cement mix doubled the strength with the same binder content. This also reduced the binder cost by half. Furthermore, different sand particle size distributions were evaluated in the laboratory where the solids content is approximately 75% by weight. A target value of 25 weight% passing 20 microns was chosen based on the results from these tests.

Since the start, several other binders have been studied in the laboratory. Among them was fly ash from different paper mills in a 100 km radius from the mine. The study showed that some of the fly ash products gave good strength development, but reaction times could be very fast and variation in quality was too high to give acceptable reliability. In addition, aluminium and silica-based slags from a steel factory in the region were tested but gave very low strength values. More recently, studies with grinding hyttsand, the raw material from the Swedish supplier, at the paste fill plant have shown consistent results. Also, laboratory tests with iron sand (Jia et al. 2016), a slag product from the Boliden smelter Rönnskär, blended in the paste recipe to change the particle size distribution for the sand show a significant strength gain (Figures 4 and 5). The iron sand is not ground, only blended in the mix. However, the iron sand has very sharp edges that may lead to increased wear of the backfill pipes. This concern needs further investigation.

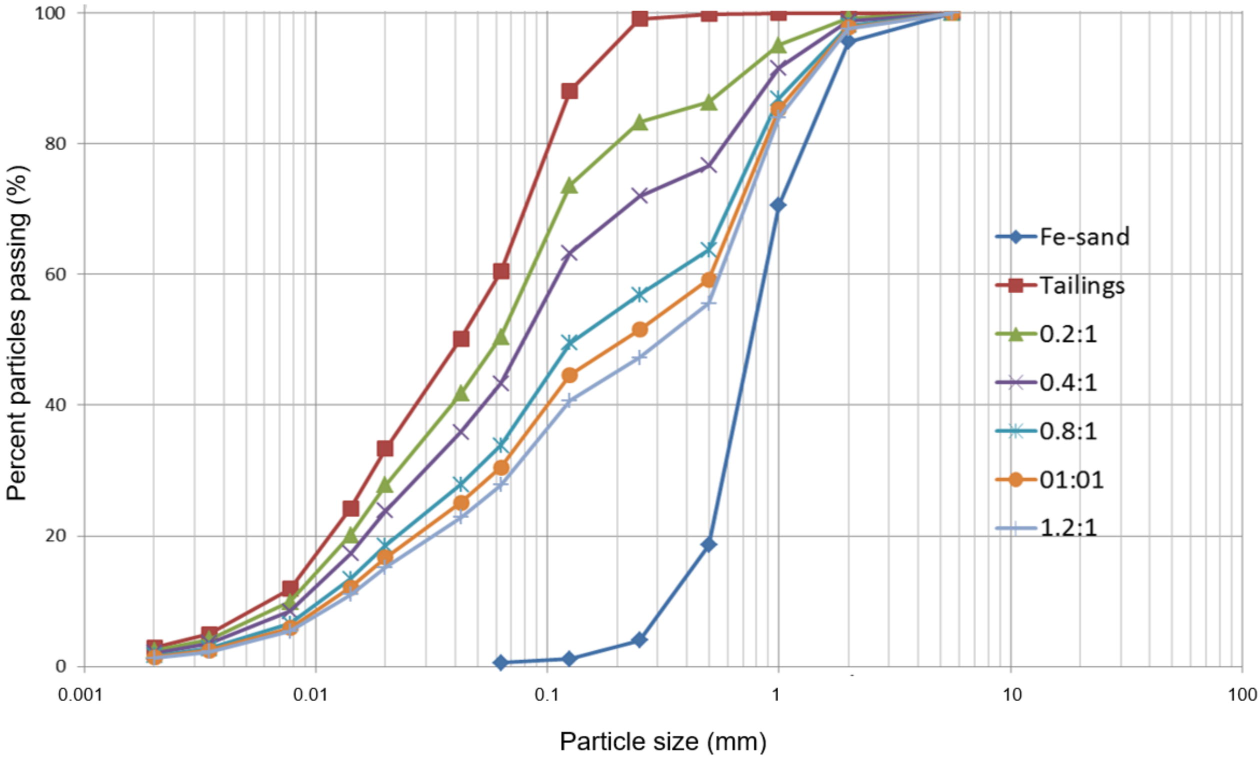

Figure 4 Particle size distribution for blends of iron sand (Fe-sand) and tailings

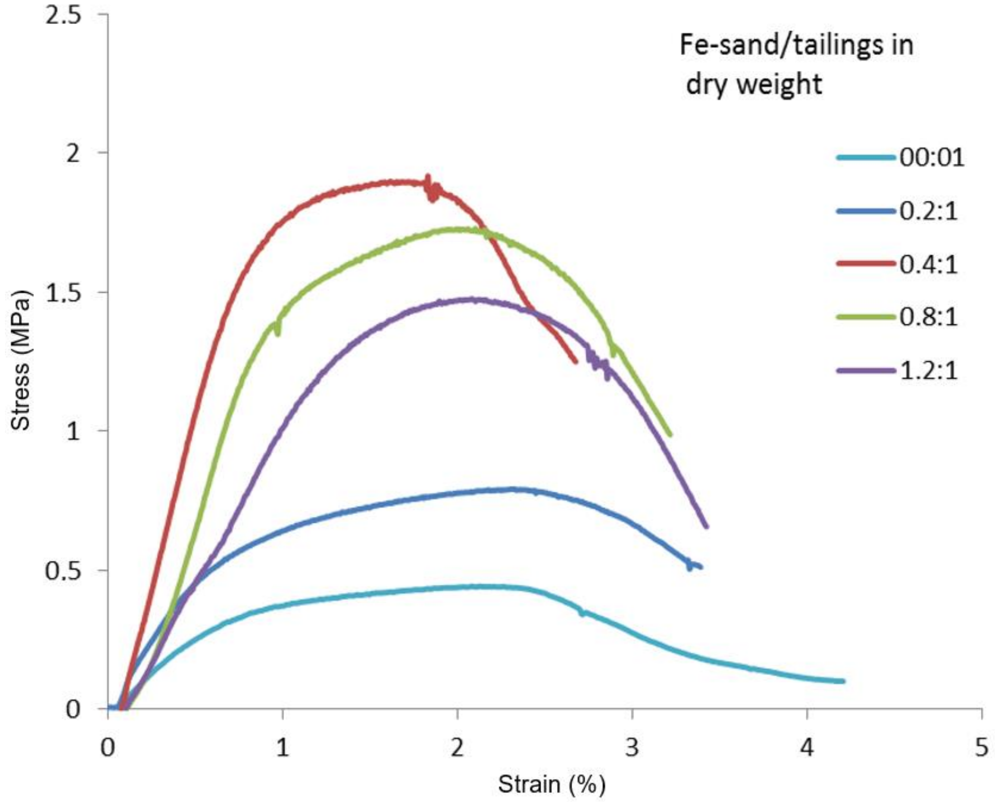

Figure 5 Unconfined compressive strength (UCS) values for blends of iron sand (Fe-sand) and tailings. The binder is an 80/20 slag/cement mix and binder content 4% by weight solids

Despite the different promising alternatives for paste recipes shown here, Boliden currently buys GGBS from a European supplier where the strength increase is considerably higher, and even though the cost for the slag and the cost for transportation is more expensive, the total binder cost has been reduced by lowering the binder content in the paste. A UCS strength of 1 MPa after 28 days for an 80/20 slag/cement mix is achieved with a binder content of 3.5 weight% solids.

4 Quality assurance

Over the years, quality assurance has developed, and today there is an onsite laboratory to follow up on paste quality in the paste fill plant. On a few occasions, core drilling has also been done in the paste backfilled stopes. Before the construction of the onsite laboratory, a penetration method was developed for estimation of UCS strength for paste fill samples from the paste fill plant. A spike attached to a Mecmesin 500N load cell penetrated cured paste backfill in a bucket. The calibration of the Mecmesin was done in-laboratory where correlation between UCS testing and the penetrating tool gave reasonably good values. A challenge with the method was strength variation in the paste fill samples because of water bleed resulting in a weak paste layer on top of the samples.

Today, paste backfill for strength testing is collected during running production from a hopper below the batch mixer. The paste backfill is poured into cylinder specimens and stored in 20°C water for curing. Before UCS testing, the samples are cut to 200 mm lengths (cylinder samples 100 mm diameter). In the onsite laboratory, the samples are measured and weighed for density calculation. The UCS tests are then done with a Matest Unitronic multipurpose frame (Figure 6). The data is stored in an Excel database.

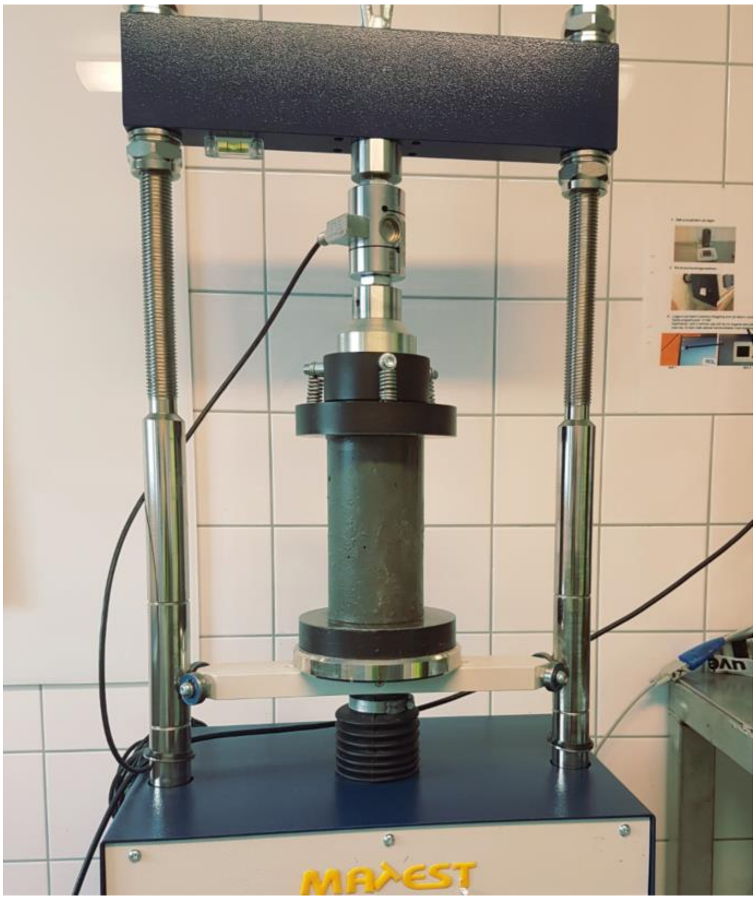

Figure 6 Unconfined compressive strength testing of paste backfill

The UCS testing of the paste samples shows that there is a strong correlation between binder content, curing time, density of the specimens and UCS strength (Figures 7 and 8). Slump tests are taken every third hour during paste production but show weak correlation with UCS strength. However, there is a strong correlation between slump values and mixer effect, which can be used to keep track of changes in paste consistency.

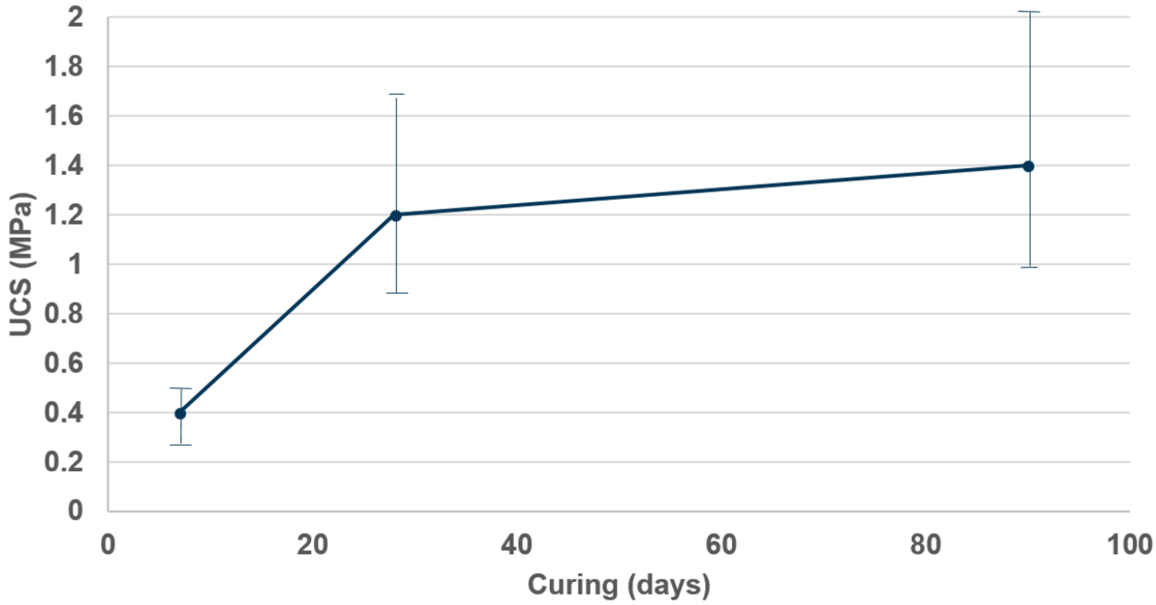

Figure 7 Unconfined compressive strength for 3.5 % by weight binder content

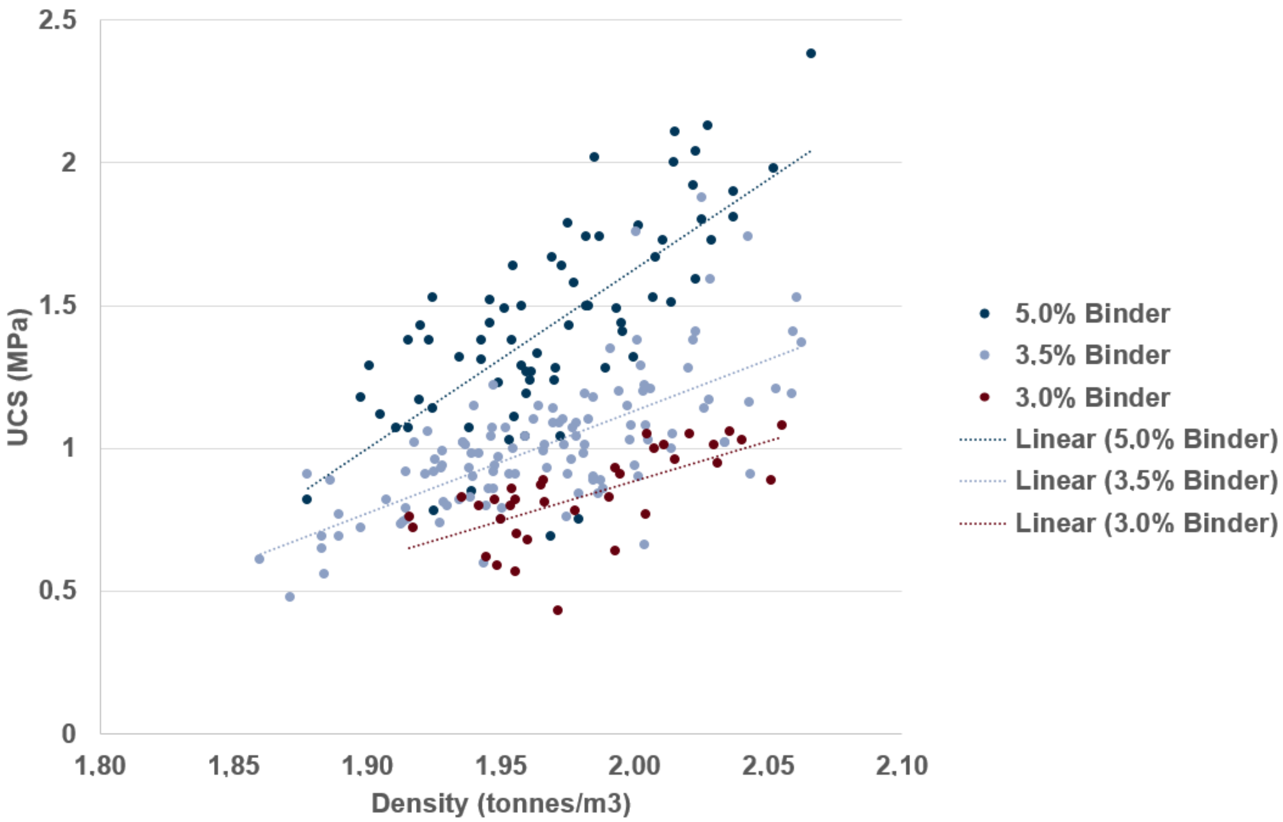

Figure 8 Relation between UCS and density

Drilling of drill cores in paste backfilled stopes has been performed at a few locations. Where underhand open stoping is used at the mine, development through paste backfill is performed. This gives access to the paste backfill, and 100 mm diameter drill cores from the paste backfill walls have successfully been obtained using a drilling machine constructed for drilling holes in concrete (Figure 9). The results from the core drilling have proven that the UCS values given from tests in the onsite laboratory are valid and can be used for quality assurance.

Figure 9 Drilling in the wall of a paste backfilled drift

5 Paste fill plant

The demand for paste backfill due to higher ore production has increased from 300,000 to 1,000,000 t per year (Figure 10). This demand has been met through several changes in the paste fill plant.

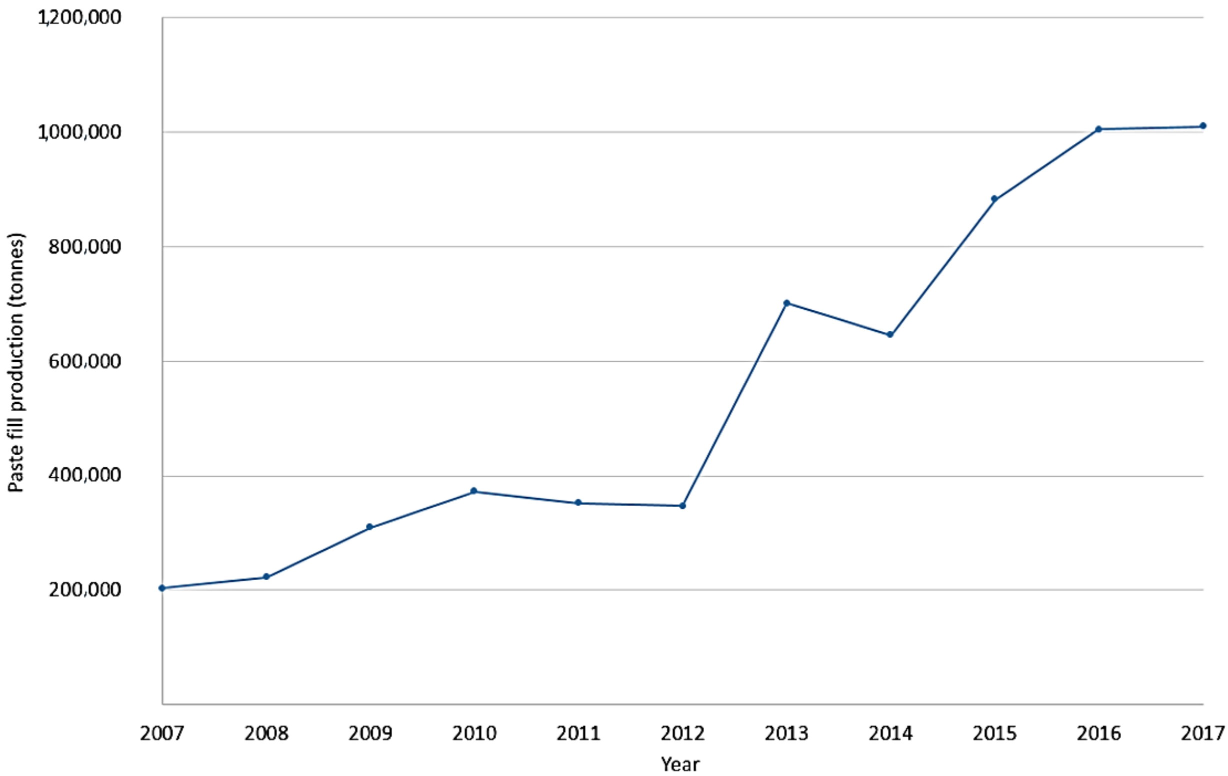

Figure 10 Paste backfill production

In 2012, the drum filter was removed in favour of two disc filters, which greatly reduced downtime for cleaning and maintenance. At the same time, one more Putzmeister positive displacement pump was installed together with an S-tube valve, which gave a reserve reticulation system in case of problems with the pump or the reticulation system (Figure 11).

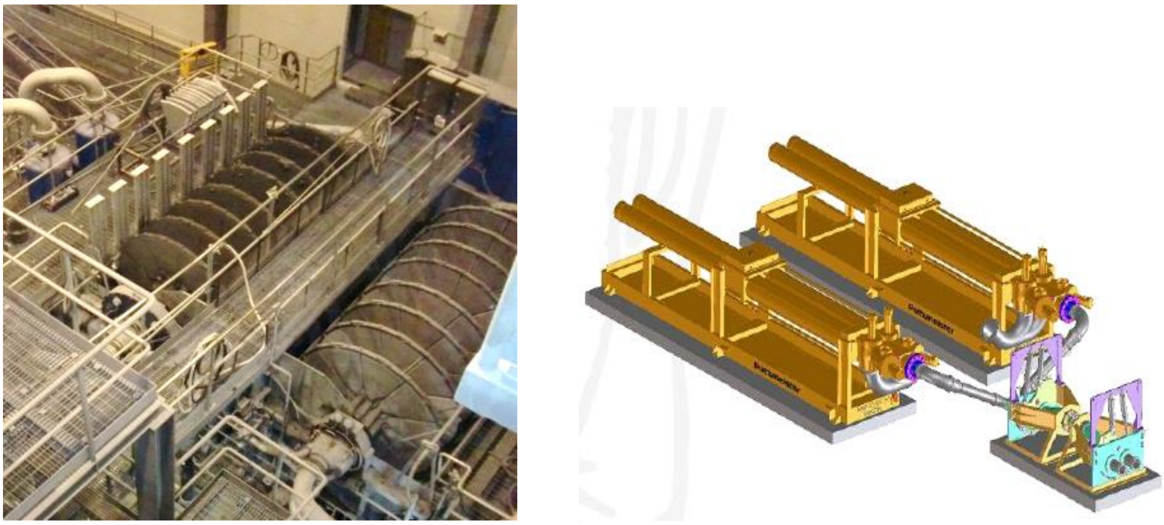

Figure 11 Disc filters and Putzmeister positive displacement pumps with S-tube valve

A project to double the production capacity of paste backfill in the paste fill plant in late 2018 is ongoing. This will give the necessary production capacity for a planned ore production increase in the coming years and reduce the availability demand on the paste fill production from close to 94% today to approximately 70%. A second paste fill production line will be installed during running production (Figure 12). This production line will use continuous mixing instead of batch mixing and among other changes, a colloid mixer for the binder.

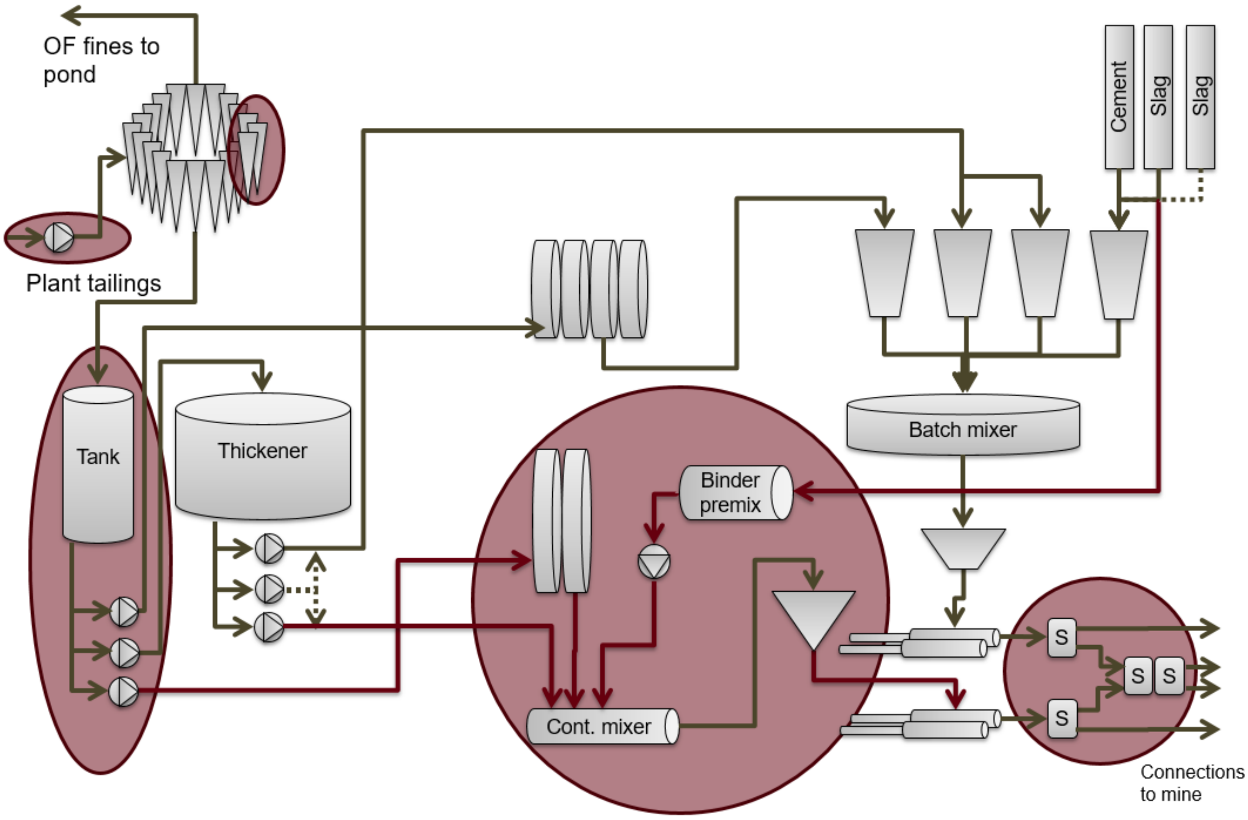

Figure 12 Simplified new paste fill plant flowchart

6 Underground reticulation system

At the start of paste backfilling in 2007, the reticulation system consisted of two pipe fill systems down to the 865 m level where steel pipes (ASTM International 2004 (168.3*10.97)) were grouted in drillholes. The paste backfill was running too fast, thus inducing cavitation in the pipes, and the wear of the pipes was very high. Paste backfill leakage was a serious problem due to wear of the pipes and because of excessively long high-density polyethylene (HDPE) PN16 DN125 pipes at the filling levels that would break under high fill pressure.

In 2008, pipe elbows were changed to CastoTube elbows, which reduced the wear at the elbows but instead moved the wear to the straight steel pipes. In 2010, thermoplastic steel pipes (Alvenius) were introduced at the filling level underground with increased diameter to reduce pressure. The maximum length of HDPE pipes used at the outflow at the stope was also shortened to 100 m. This solved the problem with breaking pipes at the filling level. In the same year, two new drillholes were drilled down to the 865 m level because the first two were almost worn out. These two new pipe systems were also grouted steel pipes in the drillholes. In 2012, a project started that would go on until 2015 to drill another two drillholes from surface down to the 1,060 m level and then continue down to the 1,232 m level. The space for drilling drillholes was decreasing rapidly so it was decided to leave the pipes ungrouted in the drillholes. A console was constructed to hold the pipes at both ends of the drillhole (Figure 13). The idea with the console was to be able to rotate the pipe in the drillhole three times before it would wear out and to be able to change to a new pipe when needed. This can be done in a week for a 200 m pipe.

Figure 13 Console to hold the backfill pipe in a drillhole

In 2014, the mine started to change the steel pipes to CastoTube pipes (Figure 14). This has proven to be successful and pays off even if the CastoTubes are four times more expensive. Today, new drillholes with a diameter of 350 mm are limited to 240 m in length and the slope angle is between 45 and 72 degrees. In the drillhole, 4.5 m long CastoTube pipes are welded together and installed. The pipes are then attached to the console. At the same time, the horizontal distances for the pipes were increased to slow down the paste fill flow to 1.15 m/s today. Since 2015, a flow of 1,800,000 t paste backfill has gone through the first CastoTube pipe that was installed underground and it is still intact without having to rotate the pipe.

Figure 14 Wear after 680,000 t of paste backfill through a CastoTube (left), and a normal steel pipe (right)

In 2015, Victaulic divert 725 valves were installed in strategic connections which made it possible to continue paste filling between stopes without any stopping (Figure 15). The change from backfilling one stope to start filling the next stope used to take 12 hours but now only takes a few minutes. The valves are mounted in a cradle to make maintenance easy. In total, there are 10 Victaulic divert valves used in the mine and these are regularly checked for wear. The first one installed is still in operation and 1,800,000 t of paste fill has gone through the valve. The valves are also connected to the ABB 800XA process system and can be controlled from the paste fill plant. This can also be done in the mine via Wi-Fi using tablets with the ABB 800XA-system software. The tablets also give access to monitoring and adjustment of pressure transmitters as well as cameras showing the reticulation system. There are 20 mobile cameras and 10 permanent cameras underground.

(a) (b)

Figure 15 (a) Victaulic divert valve (a); and, (b) Electric switch

In the same year, 2015, a collaboration was initiated with Paterson & Cooke to investigate what measures should be taken to reduce wear in the reticulation system. A permanent pipe flow loop was built next to the paste fill plant using both regular steel pipes and CastoTube pipes. Their recommendation led to the decision to use different slump values for different backfill locations in the mine. Today, the slump value is chosen based on pipe pressure, which should be of the order of 20–25 bar. Fifty pressure transmitters (Cerabar PMP75) are installed in the pipe system for this purpose. Slump values between 150 and 210 mm are used, and UCS tests show that variations in strength of the paste backfill are negligible for these slump values.

In total, there are 7,500 m of pipes in drillholes, 5,000 m of horizontal pipes to reach all locations and for dynamic flow resistance loops, and 10,000 m of Alvenius pipes at the filling levels in the mine (Figure 16). The pipes in the drillholes are monitored twice a year by video camera or after transportation of 450,000 t of paste fill.

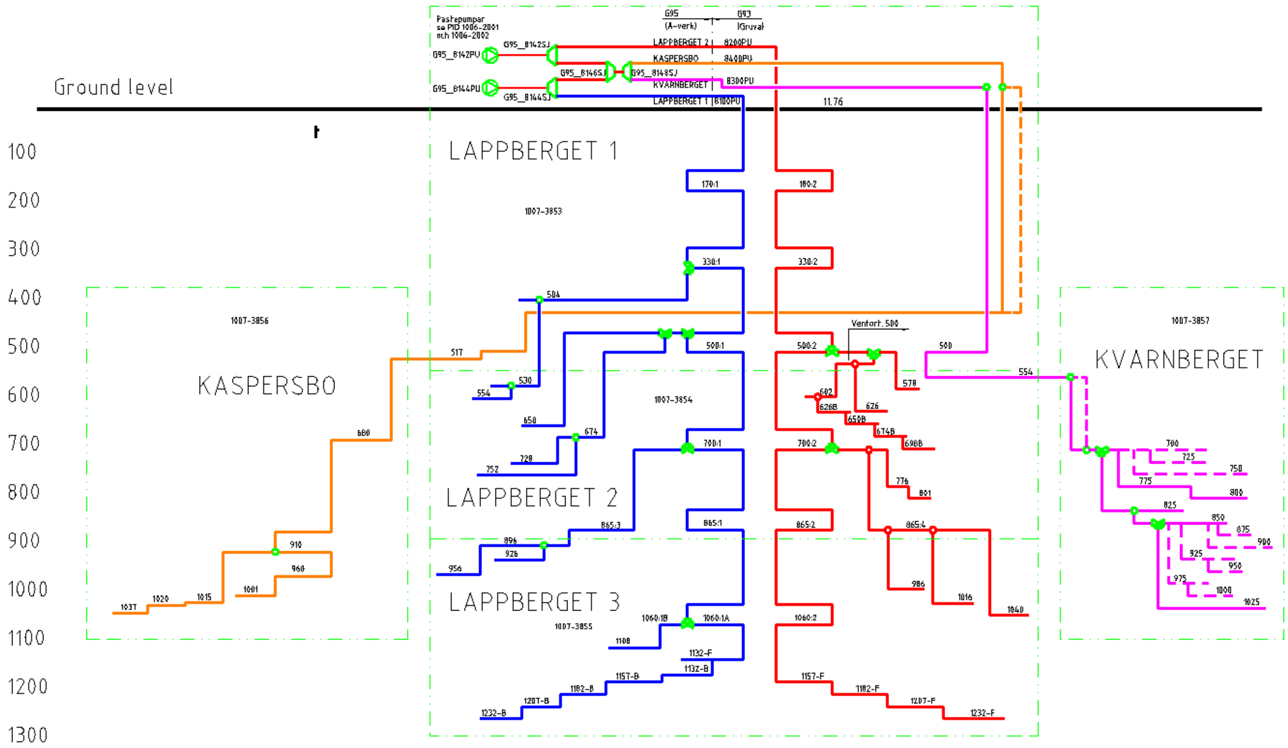

Figure 16 Garpenberg reticulation system

From the main pipes in the drillholes, branches of pipes are connected to the different mining levels. On the mining levels, standardised paste fill drifts are driven (Figure 17). Depending on the use of the paste fill drifts, different sizes are needed. The smallest drift is used to give access for backfilling stopes on the level from one drillhole. A midsize drift has an 80 m dynamic flow resistance loop and one divert valve connected to two pipes where one pipe is used for paste filling on the level and one is used for transportation to other levels. A large drift is used for two drillholes that can be connected with two valves to four new drillholes for paste fill transportation to other levels.

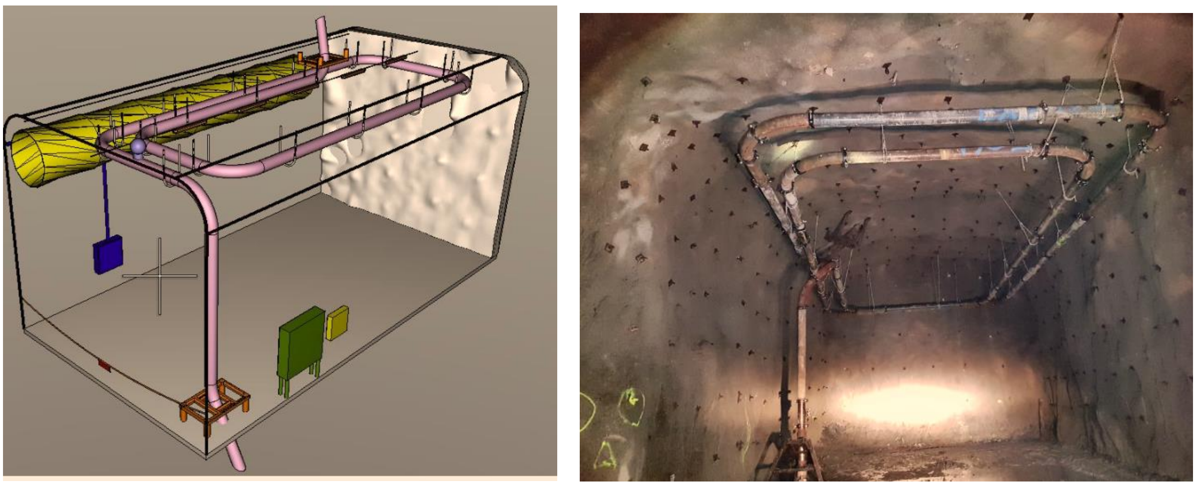

Figure 17 Mid-size paste fill drift

7 Fill fences – design and experiences

Both waste rock plugs and shotcrete fill fences are used underground. Waste rock plugs have a minimum length of 2.5 m at the top of the plug as shown as Lt in Figure 18.

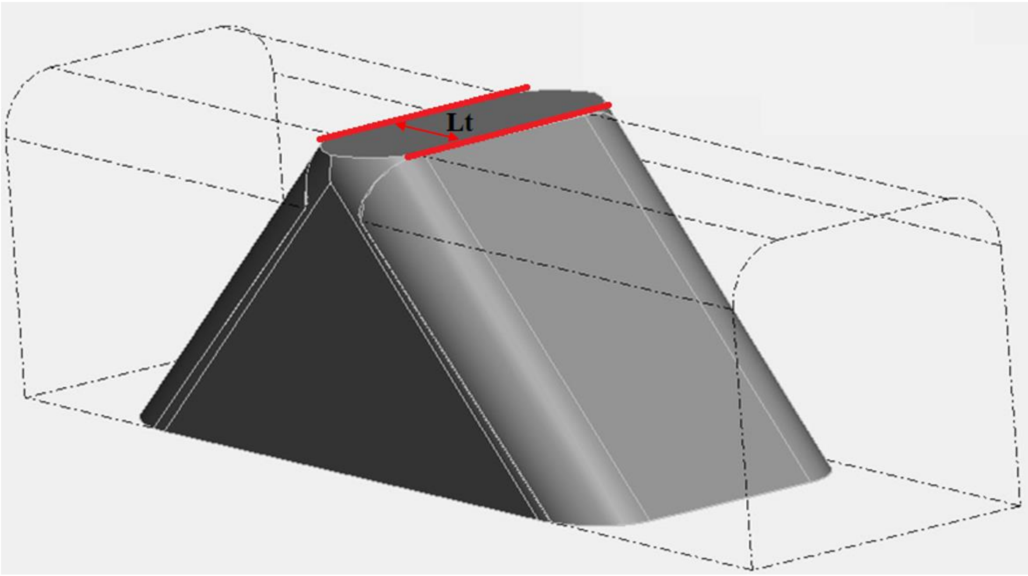

Figure 18 Waste rock plug

Shotcrete fill fences are commonly used where there is limited space for waste rock plugs, and in some areas where longitudinal open stoping is done for narrow ore lenses. The design of the shotcrete fill fences is based on numerical analysis with the conservative assumption that the fill fences should be able to handle the load from the total height of a non-cured paste backfill. In construction of the fill fence, the shotcrete strength, thickness, the radius (curved) and the connection between the fill fence and the surrounding rock are the most important factors for a stable construction. Graphs are used to give the design of the thickness of the shotcrete fill fences (Figure 19).

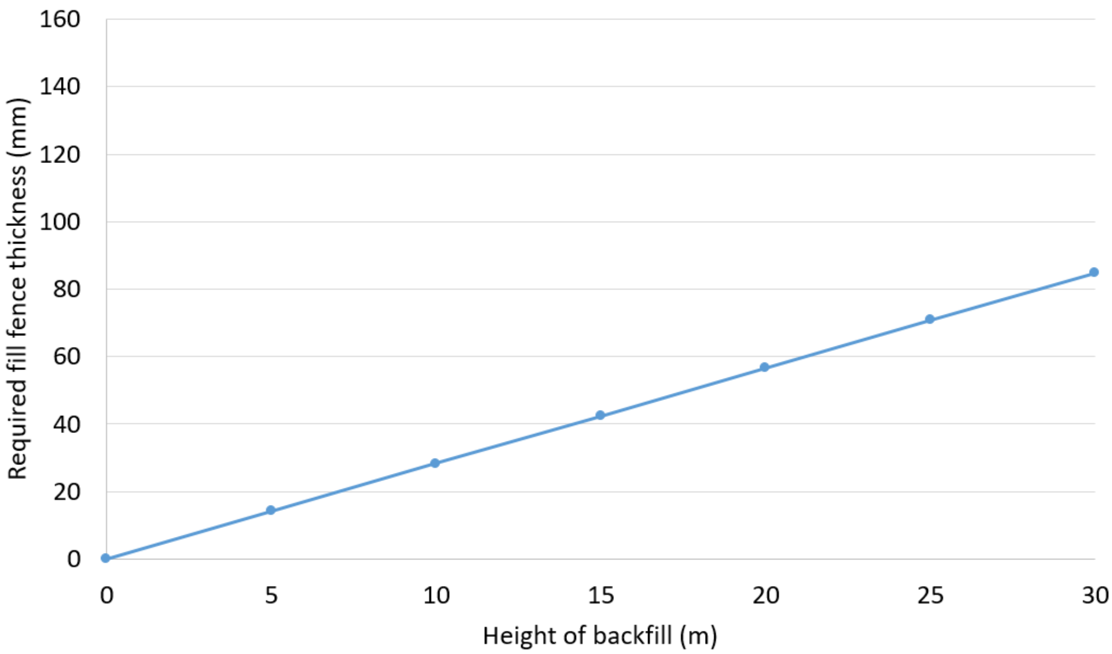

Figure 19 Relation of height of backfill pour and fill fence thickness

In a few occasions, paste backfill spill has occurred through waste rock plugs at the contact between the waste rock plug and the surrounding rock. Tension cracking of shotcrete fill fences caused by building straight fill fences where design asked for curved fill fences has also occurred.

8 Drifts in paste backfill

Development of 30 m^2 drifts in paste backfill is done by drilling and blasting. Conventional jumbo drilling of 5 m rounds are blasted. After mucking and cautious mechanical scaling, a layer of 50 mm fibre shotcrete is applied floor to floor on the back and walls. Finally, systematic bolting of a 1.5 × 1.5 m square pattern using 2.7 m long resin grouted rebar bolts is performed. Installation of the bolts is done with mechanical bolters, and is identical with installing resin grouted bolts in solid rock. The pull out strength of the bolts has been tested in a paste backfill drift with 1 MPa strength. Pull out loads between 9.5 to 16 t for fully grouted bolts have been shown.

9 Conclusion

During the 10 years of operation, the paste fill operation in Garpenberg mine has undergone several critical modifications to fulfil the demand for backfill to the mine. Large cost cuttings have been achieved through several investigations to minimise binder cost. High costs due to worn out pipes are overcome through new flow resistance loops reducing the paste flow, the implementation of CastoTube pipes in the drillholes, and the use of different slump values depending on pouring location. The onsite laboratory and underground drilling of test specimens for the UCS of the paste backfill shows consistent quality. In 2018, a major upgrade of the paste fill plant with a new production line will secure the coming increasing demand for paste backfill and reduce the availability demand at the paste fill plant from a high 94% today to 70%. The improvements over the years is a result of a working culture where committed employees have a high degree of freedom to make suggestions and implement their ideas.

Acknowledgement

The authors thank Boliden Garpenberg mine for the opportunity to present this paper. Special thanks goes to the project leader for the expansion of the paste fill plant, Mats Nordlund, for his contribution to this paper.

Reference

ASTM International 2004, *ASTM A106-04B Standard Specification for Seamless Carbon Steel Pipe for High-Temperature Service*, ASTM International, West Conshohocken.

Jia, Q, Yang, Q, Guo, L, Knutsson, S, Xue, P, Liu G & Jiang, L 2016, 'Effects of fine content, binder type and porosity on mechanical properties of cemented paste backfill with co-deposition of tailings sand and smelter slag', *Electronic Journal of Geotechnical Engineering*, vol. 21, no. 20, pp. 6971–6988, http://www.ejge.com/2016/Ppr2016.0634ma.pdf