Practical aspects of watersealing at Konkola copper mine, Zambia

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1. INTRODUCTION

Konkola Mine, arguably the wettest mine in the world, is situated in the north western part of Zambia in the district of the town of Lehililabombwe at altitude of 1330m ASL and has average annual rainfall of 1361mm.

Figure 1. Map of Zambia

The mine produces copper from an orebody with an average grade of 5% at a rate of 220 000 tons of copper per year.

Figure 2. Konkola Mine

An average of 300 000 m^3 of water per day is pumped from the mine which gives an average ratio of $\pm$ 58:1 of water to ore. This may be compared to the similar ratio of water pumped to ore hoisted at the other Zambian copperbelt mines of 4:1. Clearly this constitutes a critical commercial as well as logistical problem in the overall running of the mine.

The pump chamber situated on 985 level at No 1 shaft is equipped with 16 pumps purely for dewatering (see figure 3). Fourteen of these pumps are running on a permanent basis with the other two on standby or being maintained. The cost of pumping alone to the mine translates to between 10 and 15% of the total mining costs with the obvious implication that as mining activities increase then the above costs will also increase.

Figure 3. Pump Chamber – 985 level

Each of the operational levels are equipped with high pressure water doors which form an integral part of the emergency evacuation procedure (see figure 4). In terms of this procedure, underground workers have 27 minutes to get to safety in the event of flooding caused by a complete pump breakdown or failure.

Figure 4. High Pressure Door

2. GEOLOGY

The stratified copper deposit lies between two major aquifers as depicted in figure 5. A substantial quantity of water entering the mine comes via the hanging wall aquifer due to its connection to the surface sources of recharge. The flow to the mine is then dominated by flow through fractures and fissures which form sources of high conductivity. The proportion of water from the hanging wall aquifer is highest in the upper levels of the mine and reduces at deeper levels.

The water from the footwall aquifer is slightly acidic (pH of 6) and has an ambient temperature of 26°C,whilst the hanging wall aquifer water is slightly alkaline (pH of 7,5) with an average temperature of 24,5°C.

Due to the unsupported open stope mining method practices at Konkola, dewatering of the aquifer is required during mining operations in order to facilitate collapse in the dewatered strata subsequent to ore extraction.

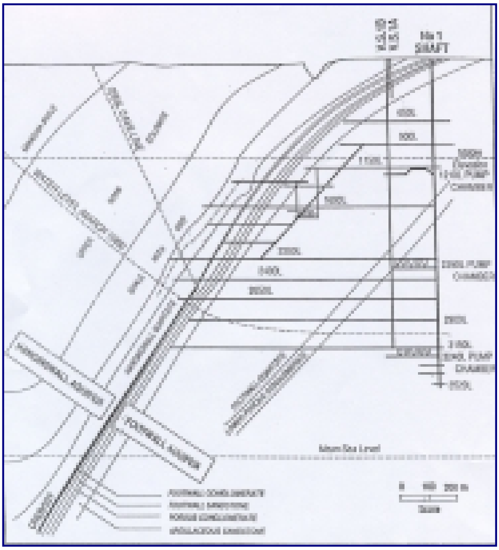


Figure 5. No 1 Shaft Geological Map

3. CONTRACTORS SCOPE OF WORK

Due to the life of the open pit mine nearing its end, the then owners of Konkola, namely KCM, launched a project to replace the surface tonnage by underground tonnage through the Konkola Deep Mining Project (KDMP)

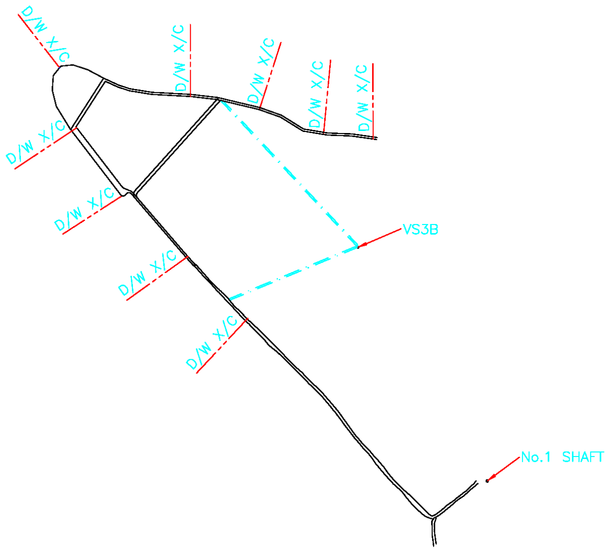
The project entailed:

a) an extension to the dewatering development on 800 and 950 levels.
b) The completion of an additional pump chamber with dams and settlers, and
c) The sinking of three shafts ie) a pipe shaft, ventilation shaft and a material and personnel transportation shaft.

On completion of KDMP, the mine envisaged having to increase its pumping capacity to 400 000m^3 of water per day.

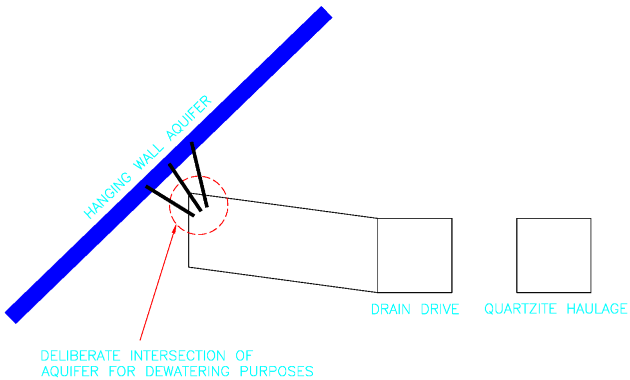
A section of the contractors specific scope of work entailed the development of a quartzite haulage measuring 4,5 metres wide by 5,2 metres high together with a drain drive measuring 4,3 metres wide by 4,0 metres high. These ends are interconnected with cross cuts at 150 metre intervals. The footwall elevation of the drain drive is 1 metre below the footwall elevation of the quartzite haulage to facilitate the flow of water from the one to the other.

Out of the drain drive, there were nine dewatering cross cuts (4,3 metres wide by 4,0 metres high) to be developed. Once the cross cuts were develop0ed to within a few metres below the hanging wall aquifer, holes were to be drilled to intersect the aquifer so that dewatering could take place. The dewatering operation of the aquifer could then be managed in a controlled manner by the installation of high pressure valves and gauges.



950 LEVEL DEWATERING

SECTION OF DEVELOPMENT LAYOUT



4. CEMENTATION METHODOLODY

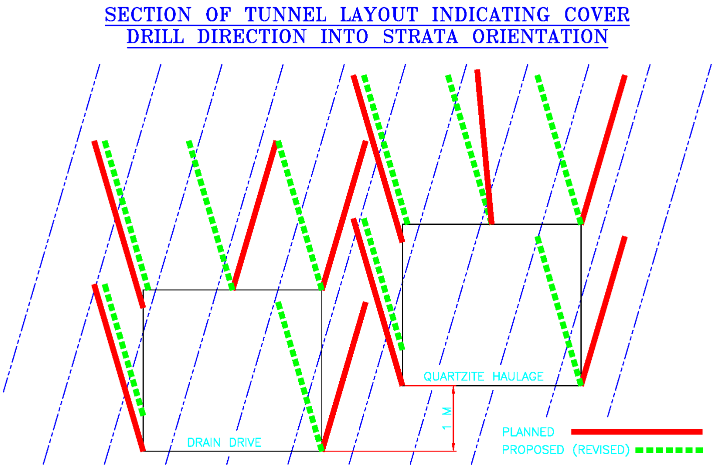
Water bearing areas were identified by the clients technical staff and brought to the attention of the contractor. In addition, the mine specified various classes of covers to be drilled which varied from no cover to a 13 hole cover depending upon the water flow intersected. The mine standard was to complete the drilling of the initial five hole cover to the required required depth of 36 metres then measure the quantity of water flow. If the collective water intersected by all the holes was less than 100 cubic metres per day, then mining would continue until the next cover position was reached.

The water was allowed therefore to flow freely from the development ends, hence the planned elevation difference between the drain drive and the quartzite haulage as highlighted in the previous section.

4.1 CONTRACTORS PROPOSAL

Based on the contractors experience from other projects, a different methodology was developed which involved the drilling of cover holes one after the other. Should the first hole intersect water, then the hole will be drilled approximately one metre past the intersection and cementation of the hole begins until sealed. This is then followed by the drilling and sealing of the remaining holes sequentially. This methodology was accepted by the project team.

Despite extensive cementation, blasting into water bearing fissures occurred even though the cementation had been completed three to four blast cycles prior to the occurrence. Further analysis of the orientation of the haulages in relation to the strata resulted in the probability that water bearing fissures would be missed on the right hand side cover. This resulted in the injection fan layout being altered to traverse the strata with positive results as shown in figure 8 below.



4.2 COMMERCIAL IMPLICATIONS

Pre-injection gives reasonable means of achieving a reduction of the water inflow to a tunnel down to a few % of the original seepage. When a very high degree of tightness is required, sophisticated methods (injection with microfine cements and chemicals, combined with post-injections) are required for removing the last part of the seepage. The costs of removing the last 10-15% of the seepage are often higher than the cost of removal of the first 80-85%.

An excessive period of time was spent on the cementation operations which was obviously very detrimental to the mine and the project as a whole. The initial stage of the project saw cementation carried out with normal OPC supplied from a local source. Utilisation of this material resulted in considerable time losses due to the setting time before re-drilling could take place and the sealing was not effective.

The resultant effect was to use microfine cement for the cementation operation on the basis of a cost/benefit analysis. Although the unit cost of the microfine cement was greater than that of OPC, the cost savings as a result of time saving related to project development more than justified its use.

The full detailed benefits of the microfine cement as well as the advantages over OPC are covered in section 5 of this paper.

5. CEMENTITIOUS INJECTION GROUTS

The decision on type of cement for the project was initially taken based on a local availability issue rather than a “fitness for purpose” criteria. As a result local OPC was utilised with the reverse effect on cost and time than was originally anticipated. The conversion to Rheocem 650, a microfine cement had a hugely beneficial effect in terms of improved production.

It is important to highlight the properties as well as advantages of microfine cement for special applications such as injection.

5.1 CEMENT TYPES

Any type of cement may be used for injection purposes, but coarse cements with relatively large grain size, can only be used to fill bigger openings. Two important parameters governing injectability of cement, are the grain size and grain size distribution. The grain size can generally be expressed as specific surface of cement grains in a given quantity. The finer the grinding, the higher is the specific surface, or *Blaine* value (m^2/kg). For a given Blaine value, the grain size distribution may vary with the important factor being the maximum grain size. The maximum grain size should be small, to avoid premature blockage of fine openings, caused by jamming of the coarsest particles and filter creation in narrow spots.

The typical cement types available from most manufacturers, without asking for special cement qualities are:

Cement Type / Specific Surface	Blaine (m^2/kg)
Low heat cement for massive structures	250
Standard Portland cement	300 – 350
Rapid hardening Portland cement	400 – 450
Extra fine rapid hardening cement (limited availability)	550

Cements with the highest Blaine value will usually be the more expensive due to the elaborate grinding required to obtain the fineness. It is generally accepted that a micro fine cement may be defined as a cement with a Blaine value greater than 600m^2/kg and a minimum of 99% having a particle size less than 40 microns.

5.2 MICROFINE CEMENT

Microfine cement have the following basic properties which make them effective for injection purposes.

- A highly grinded cement with small grain size will bind more water than a coarse cement. The risk of bleeding (water separation) in a suspension created from a fine cement is therefore lower and a filled opening will remain more completely filled.
- Finer cements have a quicker hydration and a higher final strength, which is normally an advantage, but also has the disadvantage of short open time in the equipment. High

temperatures will increase the potential problems of clogging of lines and valves. The intensive mixing required for fine cements must be closely controlled to avoid heat development caused by the friction in the high shear mixer.

The finer cements have a better injectability plus the ability to permeate into fine cracks and openings. This advantage will only be realized as long as the mixing process is efficient enough to separate the individual grains and properly wet them. In a pure cement and water suspension, there is a tendency of grain flocculation after mixing, especially with finer cements which is counter productive. It is generally stated that the finest crack injectable, is about 3 x the maximum grain size (including the size of flocculates). For standard cements, this means openings down to about 0.30mm, while the finest micro may enter openings of 0.06mm.

5.3 RHEOCEM® 650

Rheocem® 650 is a well graded cement milled from pure Portland cement clinker with a Blaine value of 650m^2/kg. The small particle size ensures that it penetrates very well into tight joints, fissures and pore spaces to provide a water-tight grouted rock or soil mass.

The grading analysis of Rheocem® 650 is shown in the table below.

	Rheocem® 650
Blaine	***> 625 m^2/kg***
Particle size	
< 40 micron	100%
< 30 micron	98%
< 20 micron	97%
< 15 micron	94%
< 10 micron	77%
< 5 micron	44%
< 2 micron	16%

It should be noted that Rheocem® 650 is a total system and not a stand alone product in that superior performance is attained when a water reducing admixture such as Rheobuild 2000PF is used. These products were successfully used in combination on the project with the latter having the effect of lowering the viscosity at a fixed w/c ratio. The effect of a lower water cement content is improved final strength as well as lower permeability and better chemical stability. In order to attain these characteristics, a dosage of 1,5% of cement weight was used.

One of the principle reasons however that Rheocem® 650 was used on the Konkola Project was the achievement of initial and final setting times faster than normal and other microfine cements. This obviously increases the productivity and hence cost effectiveness of the tunnel grouting operation. The initial set takes place within 60-90 minutes whilst the product will have set sufficiently, after 2 – 2 ½ hours to allow drilling of further control or blast holes. Other advantages related to the use of Rheocem® 650 included:

Standard cement injection equipment can be used;

- Good penetration in tight joints, fissures and pore spaces;
- Due to the greater penetration, greater water tightness imparted;
- Good working environment with no hazardous components;
- Durable and very good stability under pressure;
- Higher strength grout with practically no bleeding;
- Water/cement ratio of 1

6. PRACTICAL APPLICATION

It is essential to ensure initially that the mixing and pumping equipment have a capacity of approximately $5m^3$/hour at 30 bar pressure. Mixing of the product is also important specifically in regard to the sequence of mixing. This section will cover mixing as well as the equipment used on the project.

6.1 MIXING PROCEDURE

As will be detailed in section 6.2, the mixer is an important part of the operation with the crucial point being to ensure that all the cement particles are properly wetted with water. For this reason, a higher shear colloidal mixer was used.

The products used and the sequence of addition was as follows:

i. Water for one batch was added to the mixer;
ii. Add the corresponding quantity of Rheocem 650 (water/cement ratio of 1,0 used) and mix for two minutes;
iii. Add the Rheobuild 2000PF water reducing and dispensing admixture (at 1,5% of the cement weight) and mix for one minute

Care was taken not to exceed the designated mixing time since the intensive high shear mixing generates heat and will increase the temperature of the mix. When the mix temperature gets too high then the open time is adversely affected. If the mixing time is cut short then the flocculated clusters of microcement are not broken down by the mixer paddles.

The grout was then transferred to the agitated holding tank where the grout is kept under slow agitation at all times. In order to keep the grout fresh, the co-ordination between mixing and level in the tank is important to ensure continuous flow. The mixer should never be used as a storage vessel once again due to friction heat being generated with the resultant possibility of stiffening of the grout. As a general rule, the maximum period from mixing to application was in the order of 40 minutes.

6.2 EQUIPMENT

This is certainly an area where specific custom designed equipment should be used to ensure that the correct job is done in the most efficient and cost effective manner. The equipment package should consist of three parts:

- Mixer
- Agitator
- Pump

6.2.1 MIXER

A high shear or colloidal mixer was used on the project. This consist typically of a tank with a high speed circulation pump. The water and cement is drawn from the bottom of the tank running through the high speed impeller of the pump and returned on top of the tank. This type of mixer has an impeller speed of a minimum of 1500 rpm with the strong shearing action being utilised to properly mix, and wet the individual cement particles. In practice, the whole tank volume is fully circulated at a rate of three times per minute.

The colloidal mixer produces a grout which is much more stable and will tend to displace water rather than mixing with it as is the case with grout created by a paddle mixer. Care was also taken of the high energy created by the mixer which raises the temperature of the grout. This means that it too long a mixing time is used, then the grout could set in the mixer. One batch of grout was typically created in about four minutes and with co-ordination on the total operation between mixer, holding tank and pump, the pump was still able to operate continuously where required.

6.2.2 AGITATOR / HOLDING TANK

The purpose of the agitator holding tank is an intermediate storage vessel which keeps the grout in constant movement. It allows mixing to take place with a degree of flexibility whilst pumping is being carried out.

6.2.3 GROUT PUMP

A suitable injection pump is essential to carry out well controlled high pressure grouting in rock. The mixing and pumping equipment must allow a pumping capacity of about 5m3/hour at 30 bar pressure as a minimum. The pump itself should allow a minimum of 50 bar over pressure compared to the ground water static head.

The pump used on the project was a piston plunger type pump with a hydraulic drive system. This pumping system requires and allows independent grout pressure and grout flow control without any values or mechanical control parts in contact with the grout. The operating reliability and control accuracy are also good which is imperative under the conditions that the pump equipment was operational.

These type of pumps also have the advantage of low wear (even if abrasive grouts are pumped) and they can also operate reliably at very low output ie) a high pressure can be maintained over time at marginal or no output.

Hoses, couplings and pipes were also rated for the pressures to be utilised in the operation.

CONCLUSIONS

It is clear that the water sealing operation at Konkola Copper Mine was an exercise that needed careful planning plus the correct solution to achieve results. Within the solution were the practical aspects such as personnel training at all stages and good on-site management, together with the technical aspects such as correctly suited equipment and product.

Many similar operations have proved costly due to the lack of:

a) Proper planning
b) Close liaison with client and agreement on requirements.
c) Poor training (if any) of application personnel
d) Poor choice of equipment
e) Badly maintained equipment
f) Poor choice of sealing product

The excessive volumes of water prevalent on the mine necessitated the use of a product such as microfine cement which had been successfully used by the contractor on other mines. Certainly the change in methodology proposed by the contractor, and then accepted by the project team showed a good mutual co-operation by both parties. The commercial exercise which determined that, on a total cost basis the apparently more expensive product was in fact the most cost effective on a total project basis, was also an area where, coupled with the methodology, the client/contractor interface worked well.