Development of a cement grouted rockbolting system for use in water-sensitive kimberlite

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Synopsis

Rockbolt support of the undercut levels for the block cave at a Northern Cape diamond mine required the development of a unique rockbolting grout and pumping system.

The bolting parameters specified in the support plan required the use of cement grouts but the water present in normal grouts decomposes the kimberlite, weakening the bolt anchorage.

Minova developed a pumpable cement grout for use in the kimberlite without causing damage to the rock. The requirement was technically challenging as in addition to novel grout chemistry, the grout also had to possess adequate pumping life, fast setting and good mixing and pumping properties. A further complication was that water was not permitted in the working sections for washing the mixer and pump.

The development was a success and the resulting product, Capcem® K40P and its customized mixer and pump, have been in regular use since 2004. Use has also been extended to other diamond mines.

In a second phase of the project, innovative packing was introduced to reduce the amount of packaging material, particularly plastic film, which interferes with the diamond recovery process. This has also been successful, with an overall reduction of over 4 tons per month of packaging material.

Introduction

A Northern Cape diamond mine uses block caving to mine the kimberlite ore. Each block cave requires the predevelopment of an extensive network of drives and drawpoints in the kimberlite. During the subsequent cave, the drives must remain intact while being subjected to high and changing stresses.

The support plan for the block cave currently under development called for the use of 2.5 m x 20 mm and 3.8 m x 25 mm fully grouted tendons. A characteristic of the kimberlite is its rapid decomposition when exposed to water. Previous support systems in similar kimberlite had used either resin grouts or very low water content cement grouts such as Capram®. It was therefore logical to explore the potential of both for this project.

The case against resin was firstly its cost, which would be considerably more than a cement system, and secondly the annulus left by 20 mm bar in a 40 mm hole was too wide for effective mixing of the resin. Trials conducted with the alternative Capram® cement grout system showed that even the small quantity of free water in the grout caused deterioration of a thin layer of the surrounding kimberlite. The decomposed layer compromised support resistance.

Grouting system development

In May of 2002 representatives from the mine approached Minova with a request to develop a cement based support grout that could be used in kimberlite without creating the deterioration earlier described.

In addition to compatibility with the kimberlite, the grout had to be suitable for use with a number of tendon types and because of the closely spaced support pattern, had to be suited to a large-scale but dispersed grouting operation.

In discussion with the client, the following targets were established for grout performance

Pump life:	minimum 40 minutes
Initial set:	55–60 minutes
Pull strength:	20 kN on 200 mm of 20 mm rebar after 4 hours at 25°C.

As a pumped system it was necessary to have a relatively long working life but at the same time the grout had to be quick setting to produce the required rapid strength development. Also, the rheology of the grout was critical in that it had to be easily mixed and pumped but not run back out of vertical up-holes.

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Initial grout formulation

Experience with the Capram® grout system had shown that relatively stiff thixotropic grouts can be used, providing that a suitable pumping system is developed. Working in our favour was the low water content in stiff grouts, which results in faster setting and higher ultimate strength. For these reasons it was decided to investigate the potential for developing a stiff cement-based grout using liquid polymer in place of water. This also offered the additional advantages of not having to take water into the kimberlite area for mixing purposes and controlling liquid: powder ratios by supplying prepacked units.

The demands on the grout were a difficult challenge to satisfy, but after many false starts and disappointments a grout was created that appeared to satisfy the requirements, at least under laboratory conditions. The grout first tried had the properties shown in Table I.

This product was taken underground for trials and performed well in most respects but the pumping life proved to be too sensitive to the differing conditions in the various working places. A second formulation was produced to address this issue. Although some strength was lost, it still remained within the required parameters, while the overall usability of the material was much improved. The modified product was subjected to extensive laboratory testing, including pull strength measurements over time and with all the types of tendons likely to be used. After satisfying all requirements, the product was released as Capcem® K40P.

To ensure that the correct liquid: powder ratio was always used, Capcem® K40P was packed in kit form, each kit consisting of a box containing two bags of cement powder and a plastic bottle of liquid polymer. A pack and its contents are shown in Figure 1.

Mixing and pumping system development

The initial underground test work with Capcem® K40P was done using a standard combined mixer-pump unit (Putzmeister MP1000) and this worked reasonably well. There was, however, some difficulty in feeding the very stiff grout from the mixer into the worm pump, causing an inconsistent feed of grout into the support holes. Also, the unit was very difficult to clean, which frequently resulted in hard grout being left in the unit, particularly between shifts. This caused numerous breakdowns and high spare parts consumption.

A modified mixer/pump was designed. In an attempt to force feed the pump, a short length of auger was added to the drive shaft between the secondary agitator and the pump. This worked well and the unit was able to completely empty the mixing tank without feeding air into the support hole. The modified mixer is shown in Figure 2.

Unfortunately the modification aggravated the problem of cleaning and despite further modifications to make the various components easily detachable, the problem persisted.

Nevertheless the grouting system was performing to specification and the support programme was on track, mainly due to the support contractors who were continuously making their own changes and modifications to the equipment and devising ways to keep the machines clean. Eventually a contractor designed and built his own machine, which was a much smaller and simpler unit having fewer cleaning problems.

Further developments

This project in the Northern Cape has now been running for four years and has consumed approximately 4 000 tons of Capcem® K40P without a single reported failure. In the past year a stronger version has been developed but has yet to be field trialled.

Improved application equipment has been designed, including peristaltic pumps and hydraulically driven piston pumps. Some of the improved pumps are currently working on a second diamond mine development project. Figure 3 shows the appearance of bolted section of a drive after shotcreting. Note the density of the support.

Reduction of packaging material

In September 2005 mine management requested Minova to attempt to reduce the amount of packaging material being used for Capcem® K40P. At the time the product was being supplied in 27 kg units. Each unit consisted of an outer

Table I

Grout properties

Test	Result
Relative density	1.82
Initial set (minutes)	55
Final set (minutes)	69
Pot life (minutes)	40
Yield per kit (liters)	11.77
Compressive strength (MPa)	
4 hours	5.13
24 hours	9.29
7 days	10.29
14 days	12.21
21 days	13.28
28 days	16.77
Pull strength (kN)	
4 hours	20
24 hours	25
7 days	30

Figure 1—Capcem® K40P Pack

Figure 2—Mixer and pump

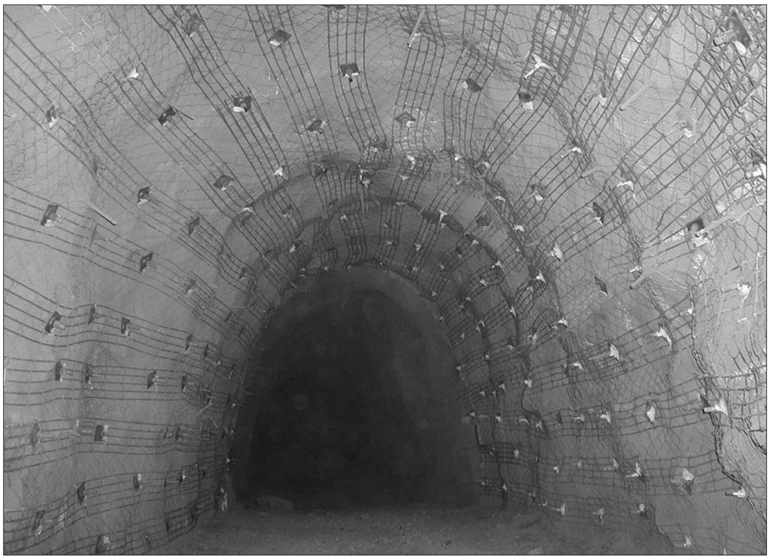

Figure 3—View of bolted tunnel

container of heavy-duty cardboard, containing two plastic-film bags of powder component and a 4-litre plastic bottle of the liquid component (shown in Figure 1).

Investigation showed that the use of Capcem® K40P was generating the following monthly quantities of waste packing, being disposed of on the mine:

➤ Cardboard	4 600 kg
➤ Plastic film	424 kg
	3 000 m^2
➤ Bottles	24 m^3
	708 kg

The volume of packaging material was creating a waste disposal problem and there was particular concern about the use of plastic film bags, as film that entered the ore stream had been identified as interfering with the diamond recovery process. There was a similar concern about the plastic bottles.

Minova established an internal project team to work with the mine to reduce the problems caused by the packaging material. The objectives of the project were established as:

- Elimination of plastic film bags
- Reduction in total quantity of packaging material
- Recycling of remaining packaging material, where possible.

These objectives were to be accomplished within the established material handling and storage practices on the mine, both on surface and underground, and without compromising the protection that the packing had to provide to the contents during transport, storage and final dispensing. The most important requirement was prevention of moisture ingress, as this would have caused premature aging of the powder component.

The project team examined a number of options and presented their findings to the mine staff for discussion in October 2005. Most options involved conversion from unit packs to bulk packs of various kinds.

The most radical proposal was for delivery of all materials to the mine in bulk tankers. Minova would have erected a packing operation on the mine, to transfer the bulk materials into dedicated mobile dispensers, holding about one ton

Figure 4—Bulk packs and inner paper bag

each. The dispensers would have been used for transport to the working places underground and then be returned for re-filling. This option would have resulted in the greatest reduction in packaging material but required high capital expenditure for manufacture of the large number of dedicated dispensers.

From the discussions it emerged that bulk container handing capabilities differed on the various operating levels of the mine. The section with the largest consumption had mechanical equipment that could handle bulk packs of up to approximately one ton without difficulty, but a smaller section had no bulk container handling capability and could receive only product in unit packs suitable for man-handling. Two parallel approaches had to be pursued one for the mechanized section and one for the manual section.

For the mechanized section, the solution tried was a semi-bulk system. The powder component was packed into 11 kg paper bags, grouped into one-tonne mini-bulk outer bags for protection and transport. For further protection during this phase, the bulk bag was shrouded and lightly stretch-wrapped. The shroud and stretch-wrapping was removed in the surface store before issuing. The liquid component was packed into 200ℓ steel drums. The volume of liquid in each drum was calculated to equal the amount needed for mixing with the contents of one mini-bulk bag of powder. The two components were supplied separately and the containers brought together at the working places.

For the non-mechanized section, the only improvement achieved was the replacement of the plastic film bags with paper bags. It is interesting to note that 5-litre metal oil cans, commonly available some years ago, are no longer manufactured. The 5-litre cans would have been ideal replacements for the plastic bottles as they can be separated from the ore by the tramp-iron magnets.

The most significant risk to both solutions was that the paper bags might provide inadequate mechanical and moisture protection to the powder. As packing of paper bags required investment in new equipment by Minova, a trial was run using paper bags packed by a sub-contractor. The trial was successful. A second trial was also run to define and test the handling of the mini-bulk containers of powder bags and drums of liquid component. No significant issues were encountered during the trial and the decision was made to proceed with full-scale conversion. Minova built a dedicated plant for packing of the paper bags. The only additional underground activity is measured dispensing of the liquid component for each mix. Jugs were supplied, but in practice the old bottles are preferred.

Since January 2006 there has been a complete conversion to packing in paper bags, achieving the objective of eliminating plastic film packaging.

Supply to the mechanized section, which accounts for over 80% of total consumption, has been in the semi-bulk form. This has reduced waste disposal requirements by 3 900 kg per month of cardboard and 560 kg per month of plastic bottles, achieving the second project objective. The semi-bulk pack units are shown in Figure 4.

A large percentage of the steel drums and mini-bulk bags are returned to Minova for reuse. The paper bags and the remaining cardboard boxes and plastic bottles still require disposal as waste; the third objective has thus been partially achieved. The potential for further reductions has been identified and will be implemented when the present system has fully bedded down.

Conclusions

A support grouting system was successfully developed for a challenging application. The most significant factor contributing to the success was a collaborative approach by the client and supplier, from system specification through development, introduction and ongoing improvement.

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