The challenges facing Continuous Mining, using low energy rock breaking technologies

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Synopsis

Continuous Mining presents an opportunity to extract reef in the stope 'continuously' by integrating the drill and blast activity using propellants or low energy charges. To date, the majority of effort spent on Continuous Mining systems has focused on developing an effective rock breaking process (micro breaking process), and to some extent, eliminating fumes and dust.

The perceived benefits of applying low energy charges have been identified as:

- ➤ Concentrated mining yielding face advances of 40 to 60 m per month
- ➤ Lower stoping widths through better-controlled breaking
- ➤ Increase in the advance per blast
- ➤ Increase in labour productivity
- ➤ The potential to mine reefs where specific conditions make conventional mining uneconomic e.g. reefs with shales in the immediate hangingwall.

However, the ability to successfully use low energy charges to create a 'Continuous or Semi-Continuous' mining method is dependent on overcoming the following challenges.

- ➤ Improving reliability of rock breaking. This is dependent upon achieving:
  - Improved drilling accuracy, and
  - Successful stemming or gas confinement, particularly in fractured rock
- ➤ Reducing gas and dust levels
- ➤ Reducing high costs.

Through the research carried out in FutureMine, many different low energy rock breaking methods and systems were investigated. Whilst detailed results cannot be published here, the guidelines for overcoming low energy rock breaking challenges are discussed.

Introduction

The ability to increase production by sourcing ore from fewer areas should improve productivity and head grade, and reduce operating costs. In time, success may also lead to a reduction in the size of the infrastructure required, as a similar tonnage can be sourced from a reduced stoping area.

Continuous Mining is a recent initiative in narrow vein stoping to achieve increased production by applying low amounts of energy to break the rock. If successful, Continuous Mining (Figure 1) potentially offers a quantum leap in face advance when compared with conventional mining methods (including drill rigs). Thus, the success of this new rock breaking system could have a huge impact on the South African mining industry.

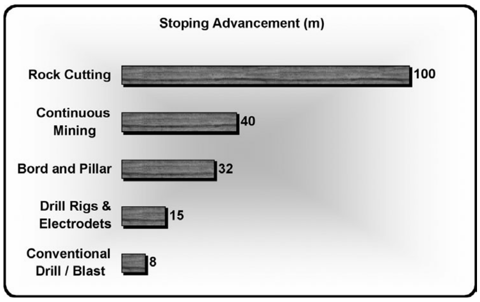

Figure 1—Monthly stoping advance for different rock breaking technologies (after Rupprecht, 2001)

Continuous mining system

Continuous Mining is a relatively new concept in the South African gold mines and offers the possibility of stoping continuously throughout the 24 hours, and monthly face advance in excess of 40 m. Current tests have focused on the actual breaking of the blast hole (i.e. the micro process) and achieving acceptable emission levels. At this stage Continuous Mining appears to be applicable to stope layouts including down dip, up dip, and breast, and face lengths between 30 and 90 m. To ensure accuracy, holes should be drilled utilizing stope drill rigs or jigs, although in some cases hand held machines are being used.

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The concept of Continuous Mining was based on a pair of holes being drilled, loaded and fired in a 4-minute cycle thereby creating a true 'Continuous Mining' cycle. More recently, this has been modified to a batch process whereby a bench of 20 to 60 holes is blasted at a time, with several blasts being fired during a shift.

Results so far indicate that more work is required to improve system reliability and to control the fumes and dust generated. Other issues such as rock handling, skill requirements, and the benefits and limitations of the system also need to be investigated. For example, indications are that the systems may be limited by depth and geotechnical areas and these issues need to be clearly understood and the constraints identified. Of equal importance is the need to clearly establish the economic benefits of the Continuous Mining process.

Drilling and charging

Accurate marking and drilling of holes is a prerequisite for using low energy charges. The drilling pattern is similar for all the systems; namely a 2-hole pattern with a burden between 200 to 400 mm. Different reefs or ground conditions dictate burden requirements and must of necessity vary to guarantee a full advance with each blast. Blast holes are drilled at either 70 or 90 degrees to a depth of 1.0 m. Drilling commences at the down dip point on the face and progresses up dip with benches drilled in 5 to 15 m lengths.

Blast holes are cleaned in the normal manner. The low energy charge is then inserted into the hole and stemming (or a stemming mechanism) is placed behind the charge. The holes are then initiated. Successful breaking appears to be very dependent upon the stemming mechanism and hole accuracy, both of which require a well trained and motivated workforce.

Health and safety

Initially it was claimed that low energy explosives produced negligible levels of pollutants, making it unnecessary to remove workers from the stope. Thus, mining operations could be continuous. However, it is now accepted that the noxious fumes produced are still above legal limits. Furthermore, although noxious fumes were the initial concern, reports now indicate that dust is also a significant problem, especially particles under 5 microns. Although suppliers now report noxious fume levels below the legal limits, there is still a concern that these levels can be consistently maintained. In one trial, for example, it was reported that levels of carbon monoxide were nine times the legal limit.

Noxious fumes

A 120 gram cartridge of emulsion produces approximately 120 litres of gases with the main content being water vapour, nitrogen and carbon dioxide, which are quickly diluted by mine ventilation. Of major concern however, are carbon monoxide and nitrous oxides, which are toxic. Regulations (10.6.6) state that less than 5 ppm of nitrous fumes and 100 ppm of carbon monoxide (CO) is allowable in the working environment. Thus, it is critical that any low energy charge must be formulated to meet these limits and be monitored on a regular basis. If workers are to remain in the stope during blasting then noxious fumes must either be removed or diluted.

Dust

The ability to manage and suppress dust is a key issue and may yet prove to be a greater challenge than fume suppression. Dust is generated along rock fracture planes as the fracturing process breaks the rock and, typically concentrations exceed the legal limit of 0.1 mg/m3. It is therefore apparent that some form of in-stope dust suppression will be required. Water sprays alone will not be sufficient because of the presence of minus 5 micron particles. High face velocities further hinder dust suppression, and inhibit the effectiveness of water sprays. Dust suppression will require further research if a permanent solution is to be provided.

Noise

Noise is considered during the blasting and is not evaluated during drilling, as this will offer the same hazard as with conventional blasting operations. During blasting, noise levels will be above the accepted level of 85 dB. Consequently, the position of refuge must account for the anticipated noise levels. Operators will also be required to use hearing protection during blasting.

Fly rock

Rock particles need to be confined to the face and the Continuous Mining systems ideally should not generate fly rock. Although the Continuous Mining systems claim to generate a minimal amount of fly rock it is still essential that with all the rock breaking processes the operators be out of line of sight of the breaking process.

System reliability

System reliability is an important issue because it affects the number of shots initiated and the volume of rock broken per blast. Because Continuous Mining employs low energy explosives, any hole that fails to fire properly will adversely affect the breaking of the remaining holes. Reliability is a function of (1) the initiation system and (2) the low energy charge.

(1) In sequence firing is vital to the success of the system, thus electronic delay detonators are used for initiation. These systems have proved to be dependable with reliability in excess of 99%.

(2) In conventional blasting it is customary to overcharge holes to accommodate frequent misfires and out of sequence shots associated with fuse/ignitor cord initiation systems. For example, in the case of a misfire, typically 2 m of face is required to recover to full advance. Continuous Mining systems using low energy charges do not offer this capability. Therefore, the Continuous Mining system must be 100% efficient. Current results, however, indicate

system reliability in the range of 87% to 95%, leading to blasts that break only a portion of the charged face. Thus, one misfire (or out of sequence shot) can halt the rock breaking process, even though each charge may have fired.

For example, a 30 m panel requires approximately 200 holes. Based on the above reliability, this equates to the failure of between 10 to 20 holes that will influence the remaining shots and thus the feasibility of the system. Indeed, with the unit cost in the region of R20 to R35 per hole, the risk of misfires or failed shots has an enormous impact on the feasibility of the system.

Rock removal

To date, focus has been placed on breaking the rock with little attention as to how the rest of the system would function. It was inferred, however, that cleaning would be achieved by water jets and scrapers. During trials suppliers have been dependent on the participating mine to solve the problem of removing broken ore from the face. If Continuous Mining proves to be successful it will be vital that rock handling systems be mechanized in order to support advances in the order of 40 to 70 m per month.

Mine layout/mining system

Another area that requires further attention is the mining layout based on the use of Continuous Mining. Continuous Mining, so far, has been implemented in conventional stope layouts. However, more work is required to determine the benefits that the new technology can offer in terms of mine layouts, for example, determining the benefits of fewer gullies, lower stoping widths and a reduction in dilution. Other areas to be considered are increasing the panel length, face advance, and the effect concentrated mining has on the operations. Detailed work is required to establish a mining cycle for bench mining, for example how support or cleaning activities are performed concurrent with drilling and blasting.

The initial assumption by two suppliers was that two holes would be drilled and fired together, breaking a 300 mm slice of rock approximately one metre deep. Drilling would take place a few metres above the charging and blasting operations creating a continuous rock breaking system, thus the term ‘Continuous Mining’. However, the system required modifications due to the risk associated with firing shots near the drilling crew and the workers were required to move to a place of safety when the blast was initiated. Both suppliers and contractors realized that the delay, while the operators retreated to a safe position, made it impossible to achieve the desired frequency of firing each pair of charges. This has prompted some companies to pursue alternate means of stemming to confine gases in the hole, while others have continued with the original concept of initiating two holes at a time.

Geotechnical areas

Trials of the available systems are limited and to date no comprehensive understanding has been gained in terms of the geotechnical areas where low energy rock breaking can be applied. It has been inferred that Continuous Mining improves the mine call factor (MCF) as fragmentation is improved and less gold is liberated when compared to conventional blasting. Generic studies indicate that Continuous Mining can improve the MCF by up to 5%.

Further understanding is required of the role that depth plays on the feasibility of propellants. As rock fracturing increases with depth, there is a greater chance that the rock will not fragment as the gas pressure is reduced as gas escapes through the fractures.

Skill requirements

Low energy explosives are designed to break the face using the least amount of energy. However, due to variations in the geotechnical environment there is a greater risk of failure than when using conventional explosives. Thus, Continuous Mining will require improved skills, as the miner must analyse the results of each blast and make corrections where necessary to achieve the desired outcome. Variables that the miner must consider are:

Hole burden and spacing	Rock type
Hole orientation, diameter, depth	Geological discontinuities
Propellant/explosive charge	Costs
Cartridge initiation	Ventilation velocity
Bench length	Operator skill
Stemming quality	Explosive charge

Cost comparison

If the Continuous Mining process proves able to break rock, there is a definite need to establish the economic feasibility of the system. Indications are that face advance alone will not justify the use of the system, and that the benefit of increasing face advance may only cover the additional cost of the system. In order to justify Continuous Mining there must be identifiable benefits, for example improved productivity and safety, or an increase in grade, MCF, or net profit, lower mining costs, or cut off grade. Ideally, Continuous Mining should create reserves from previously blocked resource identified as uneconomic when utilizing conventional mining methods.

Indications from a number of trials are that current costs are several times those of conventional explosive systems. No figures have been published but it is presumed that these estimates include the initiation system, misfires, poor breaking, etc. A simple cost comparison is presented here for illustration. Assuming a 1.0 m SW, an SG of 2.75 and 4 holes/m^2.

(1) Conventional explosive costs are: -

	R/m^2	R/t	
Drilling	11	4.0	
Explosive	37	13.4	
TOTAL		17.4	(excl. labour)

(2) Low energy systems

	R/m^2	R/t
Drilling		8 (2x number of holes)
Explosive	256	93
TOTAL		101

This theoretical calculation assumes that each charged hole will break the designated amount of rock. It does show, however, that low energy systems may be as much as six times the cost of conventional explosives. This is due in part to the reduced burden and spacing requiring a greater number of holes. In addition, with low energy explosives it is not uncommon for the rock to fail to break, or to only break the top or bottom half of the hole, thus requiring the hole to be re-fired. As a result operators will insert more than one cartridge per hole to improve reliability, adding to the cost.

While this calculation excludes possible economies of scale that would accrue were low energy explosives successful, it does indicate that there is still some way to go if such systems are to be economically justifiable. Other potential benefits of low energy explosives, such as better hangingwall conditions, reduced stope width, etc. are not considered here.

At this stage rock breaking costs for low energy explosives appear to be substantially higher than for conventional rock breaking. Hence, it is important that other potential benefits for a low energy system be well established. Key amongst these are:

- Continuous Mining. Although still subject to the drill, blast, clean and support cycle of conventional mining, they have potentially broken the stranglehold of timed blasting with a predetermined re-entry period. Thus, it should be possible to achieve higher rates of face advance. In a well-managed operation higher rates of face advance will realize some saving in infrastructure operating costs. In a mine that is not achieving production targets, it could make a substantial impact on profitability.
- Improved stope width control and hangingwall conditions due to a more controlled rock breaking process. In gold mines, the blast tends to break to a parting. With a less violent rock breaking process, it should therefore be possible to exercise greater control over stope width. (However, it might be questioned how much benefit would be realized if the same effort were to be put into improving conventional mining practice.) Along similar lines, there should be an improvement in hangingwall conditions, as there is less blast-induced damage (fracturing). Up-side potential to this could be a reduction in support requirements and possibly a reduction in FOG risk.
- Concentrated mining will necessitate an improved transport system, possibly with less equipment and fewer people. It is projected that a greater tonnage will report to a cross cut over a 24-hour period, giving a more constant tonnage profile when compared to conventional mining, where the majority of the tonnage is transported during nightshift.
- A reduction in ventilation and pumping costs, resulting from a reduction in power consumption, as fewer areas need to be serviced. Long term, this could also bring about a reduction in labour, as fewer workers are required in service departments, commensurate with a reduction in infrastructure requirements.

Problems envisaged

Continuous Mining requires accurate drilling making the use of drill rigs/jigs mandatory. However, to date drill rigs/jigs have had limited success in the South African gold mining industry. Hence, there may be resistance to utilize drill rigs/jigs leading to the continued use of hand held drills, and to the detriment of low energy systems.

Drilling costs increase, as Continuous Mining utilizes twice to three times as many holes as conventional blasting.

Increase in explosive costs per hole. Explosive costs are significantly higher than conventional blasting. To this must be added the cost of electronic initiation systems. If a hole fails to break, there will be further costs for recharging and initiation of any additional holes.

In highly fractured rock, the hole being blasted may not break as the confined gas dissipates into joints and fractures. In trials deck charges have been utilized to overcome this problem. In contrast, where hard rock (~10%–13%) is encountered the burden must be further reduced (200 mm) requiring more holes and higher blasting costs.

A high degree of skill is required to manage the Continuous Mining systems, as the breaking requirements can change from blast to blast.

The way forward

As a rock breaking method for use in stopes, low energy systems have so far not lived up to expectations. The key to the use of this technology is the ability to contain the gases within the hole, long enough for them to do their work. Here, natural and blast induced fractures and stemming are all key factors. This suggests, for example, that the use of this technology in fractured ground might be inappropriate, i.e. at depth, even if new stemming methods or materials are developed.

Other than lining the blast hole, can anything be done to reduce the effect of fracturing on the performance of low energy explosives? It is suggested that even if lining were practicable, it is likely to be costly. If low energy charges prove to be unsuitable for gold mine stopes, is there, perhaps, another application? A number of possibilities present themselves, including:

- The use of low energy charges to fracture 'hard patches', thus enabling the use of an impact ripping system.
- Reducing the level of blast induced fracturing in stope gullies for narrow vein long hole stoping.
- Sliping, and the excavation of areas sensitive to blast damage, for example at stations, established breakaways or near equipment. In these applications low energy explosives would compete with mechanical methods and expanding chemical grouts, where price is not such an issue.
- To employ low energy explosives in areas of weak hangingwall, e.g. shales, permitting a reduction in stope width and increased safety.

Conclusions

To date, the results of underground trials suggest that the practical problems associated with consistently and repeatedly breaking rock with low energy explosives have not been overcome. Approximately 8% to 13% of the holes fail to break and the failure of just one hole is sufficient to stop the rock breaking process. This has prompted at least one supplier to reconsider stope production as an appropriate application.

Further concerns are the levels of noxious fumes and dust generated by low energy charges. Although there are no issues regarding gas and dust that are insurmountable, some development work is necessary to ensure that adequate system features and protective measures are made available to mine operators. This will limit workers' exposure to toxic atmospheres and maintain other hazardous conditions within acceptable limits.

If the above technical issues can be resolved, there remains the issue of the feasibility of Continuous Mining as a rock breaking system, as current indications are that the process is considerably more expensive than conventional blasting. A proper cost benefit analysis of the system is therefore required. However, before this can be done a complete mining cycle and mine layout must be developed.

Acknowledgements

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World acclaim for Sasol's high-achiever mines*

New York—Sasol Mining recently received the prestigious international Coal Company of the Year Award in the 2002 *Platts/Business Week* Global Energy Awards presented in New York City (Monday, 18 November 2002). The award is in recognition of Sasol Mining's ability to sustain business and human growth and prosperity through an ongoing process of focused and successful business renewal.

Sasol Mining is an integral part of the Sasol Group of companies and is responsible for producing and supplying about 50 million tons of coal a year, mostly to the Sasol factories at Sasolburg and Secunda, South Africa and to international customers.

Sasol's chief executive Pieter Cox said last night: 'This is a significant award for South Africa, especially the coal-mining sector and is a fitting tribute to the vision, diligence and passion of Sasol Mining's people over the last four years since implementing their comprehensive business renewal process. Previous managing director Jannie van der Westhuizen and his successor Riaan Rademan, and the team at Sasol Mining have unlocked a substantial amount of new value especially in the coal mining sector. These achievements support the Group's growth strategy and significantly improve our competitive feedstock position in the production of liquid fuels and chemicals.'

Managing director Riaan Rademan says 'Despite the country's often-difficult geological conditions and the severe competition from some of the world's other leading coal producers, notably Australia and the United States, Sasol has demonstrated that South Africans can rival international best business and mining practices.'

Sasol Mining continues to aspire to achieve and maintain world-best practices in the fields of human resources development, occupational health and safety management, as well as environmental management.

In addition, the company has implemented several major technological advances in key areas such as virtual mining, directional drilling, mine planning, coal cutting, coal handling and ventilation. ◆

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Target Gold Mine project completed

Target, a division of Avgold Limited, is a new mine situated north of Welkom. The R200 million (approximately US$ 25 million) metallurgical process plant was officially opened in March 2002 and is capable of processing 105,000 tonnes of gold-bearing ore per month. It is the first large 'grass roots' gold mine that has been developed in South Africa over the past 20 years. Target had the option of processing their ore through the fifty-year old Loraine Gold Mine plant or building a new facility. A study was carried out with Hatch Africa for a new processing plant and, at the same time, Batemans Minerals and Metals Limited were used to evaluate the economics of rehabilitating or even simply maintaining the old Loraine plant. From those findings, it was concluded that a completely new plant was the answer.

Avgold did not have the capacity to design and construct a new processing plant so the services of an external design company was elicited. The costs involved in quoting on a job such as Target are substantial so an initial list of fourteen companies was short-listed to five before going out to tender. Signet Engineering, a wholly-owned subsidiary of Fluor Daniel, was finally selected because of their recent gold experience around the world.

'This award constitutes a landmark in terms of innovative Australian concepts coupled with proven South African design technology,' says Jeff Gard, president of Fluor Corporation's Mining and Minerals strategic business unit. Detailed design was carried out at Fluor's office in Perth, Australia, and on completion, responsibility for construction was transferred to the site office at Allanridge in the Free State. A number of people on their project team had experienced local conditions and were well aware of the problems that exist on South African operations.

The majority of the materials and equipment were sourced from suppliers within South Africa. The main sub-contractors included South African companies well recognized in the industry. These included LTA Grinaker for bulk earthworks and concrete construction, Girder Naco for fabrication and erection of structural steelwork and mechanical installation, Kentz for piping installation, B&W Industrial Technology for electrical and instrumentation supply and installation, and finally, Goldfields Development for plant buildings.

During construction, employment on site peaked at over 500 people. The project, which was completed within 12 months, expended over 888 000 man-hours without a single lost time accident.

The project team visited South African and Australian operations to evaluate the technology and layout design. This exposure along with the Target philosophy was used to draw up the design criteria for the Target Metallurgical Process Plant (MPP) and was designed for a 15-year life and to cope with the future expansion from 105 000 tpm to 160 000 tpm. The drive at Target is to achieve best cost efficiency by minimizing labour and maximizing automated process control. These guidelines were used to design the MPP. In minimizing labour the MPP design had to be such that it would be easier for people to do their jobs. Rapid pedestrian access has been facilitated through the installation of walkways interconnecting at the same level.

The design included the complete process, structural mechanical and electrical design, and addressed basic issues.

- Keeping all pulleys and steelwork above ground so they would not be flooded periodically
- Taking pulleys out from under structures so that they were accessible when bearings needed to be replaced
- Ensuring that equipment such as pumps and motors were positioned so that they were both accessible and could be hoisted and moved for repair
- To counter the availability problems of mobile cranes, electric hoisting jibs were installed in key areas.

Testwork was conducted on the Target ore by Mintek and Anglovaal Research Laboratories.

The feed from the shaft to the silo is designed to handle 400 tph whereas the rest of the MPP is rated for 162 tph so the shaft system can quite easily cope with 160 000 tpm. From the silos feeding the mill, through to the smelt house, the MPP is all designed for 105 000 tpm so additional equipment would have to be installed if the tonnage throughput is expanded. The smelt house currently is designed for 105 000 tpm as a one-shift operation. Additional floor area has been allowed in the smelt house so that if the need arises another bank of electro-winning cells and another smelt pot could be installed to handle the expansion.

The problem of oversized rocks and tramp material coming up from underground has traditionally been a headache for metallurgical plants, a problem mining people have literally passed on to the process people. However, crushers have been installed underground with the accompanying conveyors, so the maximum lump size can be controlled and managed.

Process control systems have improved rapidly over the past couple of years and the emphasis was on obtaining reliable data for managing the operation. The Target MPP process control uses a SCADA system, with numerous PLCs and instrumentation in the field. The design examined process control and the level of control rather than full automation.

Avgold opted for proven rather than cutting-edge technology with one or two exceptions. The leach circuit has been designed conservatively, to take full tonnage and full grade. Running parallel, there is a gravity circuit that includes a Knelson concentrator. Gold plants in South Africa have tended to avoid gravity concentrators simply because of the security risk. At Target, the smaller workforce has diminished the security risk relative to the old operations employing 200 or more people. Recently in South Africa there has been a trend to go back to using gravity extraction of gold. About 40% of the gold is recovered using this gravity circuit. Another innovation is the Gekko reactor that carries out a high intensity leach process. the gold concentrate is exposed to high levels of caustic, cyanide and oxygen to dissolve the gold. Effectively, it is a revolving drum in which the gold is dissolved, the process taking a number of hours. It is a batch operated process with the subsequent flow joining the electrowinning circuit.

The residue from the MPP either reports to the backfill plant or directly to the existing Loraine tailings dam. When the backfill plant is running the reject material is pumped out to the tailings dam via the MPP. Longer term, it is envisaged returning tailings dam water to the MPP as part of the environmental drive.

The MPP employs 54 people to carry out the operating and maintenance of the MPP and the backfill plant. The MPP runs on two 12-hour shifts with three operators per shift; the artisans all work on day shift. The backfill plant was outside the scope of Signet design.