PICKERING, R., SMIT, A. and MOXHAM, K. Mining by rock cutting in narrow reefs. *International Platinum Conference 'Platinum Surges Ahead'*, The Southern African Institute of Mining and Metallurgy, 2006.

Mining by rock cutting in narrow reefs

R. PICKERING*, A. SMIT* and K. MOXHAM†

**Sandvik*
†*Lonmin Platinum*

Since the early 1970s research has been ongoing to develop a cost-effective way of continuously mining the narrow reef, hard rock, typical of South African gold and platinum mines. In the late 1980s it was shown that impact ripping was a practical solution for the deep gold mines. In March 2001 Lonmin and Sandvik agreed to co-operate in an endeavour to design and manufacture a prototype narrow reef mining machine with the ultimate aim of producing such a machine on a commercial basis that would enable Lonmin to create a safer and more productive environment within its mines and for Sandvik to enhance its leading position as a supplier of a new generation hard rock cutting machine. This paper describes the developed technology, the current progress of the delivery of the required objectives and the optimum mining layout for the roll-out of the mining method.

Introduction

The hard rock gold and platinum mines in South Africa have seen little development in the technology of mining. Holes are still drilled in the rock - though the latest water hydraulic rockdrills will complete that task in two minutes compared with the eight hours for hammer hand drilling at the start of the last century. Charging up is with far safer explosives, and with available initiation systems it is no longer necessary to run up the face lighting each fuse. Movement of rock in the stope is predominately by means of scraper buckets and scraper winches - these were first introduced in the 1920s. Support is still mainly rock, either *in situ* pillars or backfill, or alternatively wood. As the mining process has changed very little, it is hardly surprising that the productivity of mining is also relatively unchanged.

Major efforts have been made to mechanize the mining process. However, most of the narrow reef mines where 'trackless mechanized mining' was introduced in the early 1980s have reverted to conventional mining. In the wider reefs mechanized mining is the option of choice; unfortunately most of the gold and platinum mines have very narrow reefs that are not suited to 'off the shelf' equipment. The move to introduce room and pillar mining into the narrow UG2 reefs is at the expense of mining more waste with the reef; fortunately it appears that appropriate waste and reef separation processes are available. Room and pillar mining followed by long hole drilling and blasting of a narrow slot of reef out of the pillars currently appears to offer the best of both worlds - maximum reef recovery with minimum waste dilution.

All these mining methods are still dependent on blasting to break the rock. The cyclic nature of mining by blasting places severe constraints on the rate of face advance that can be achieved and consequently the utilization of the invested capital. For narrow reef hard rock mining to break out of these constraints and to really make progress in the 21st century, it is necessary to follow the lead of the soft rock mining industry and change the technology of mining. In the underground coalmining industry, coal cutting has been proven to be the most cost-effective solution; in narrow reef hard rock mining the future must be based on the development of non-explosive methods of rock breaking that, in turn, are integrated into continuous mining systems.

Non-explosive mining means that the mining operation can be conducted on a continuous basis, with no delays for the removal of blasting fumes. Continuous mining also maximizes the return on the capital invested in developing the mine. Rock cutting will define the stope width and that in turn will be designed to minimize waste dilution; it will also minimize damage to the hanging and create a safer environment. Mechanization makes it possible to automate the mining process and further improve safety by positioning the operators in a safer environment.

Over the years there have been trials of a number of different cutting processes and mining machines:

- Typically cutting with picks has not been cost-effective in hard rock.
- It is well known that full-face cutting with either solid discs or cutters has been successfully applied to raise boring and TBMs. A narrow reef mining machine operating with this cutting mode has been developed and trialed by Placer Dome in a narrow vein underground in Canada, and a similar machine was trialed by Anglo Platinum. Cutting experience is limited, with only a few cubic metres of rock cut at both sites.
- Anglo Platinum used activated cutting for a stoping machine in the platinum mines and have successfully cut a few cubic metres.
- CRC Mining in Brisbane is conducting laboratory - scale experiments for oscillating disc cutting and there has been some cutting in a quarry.
- Undercutting, as a cutting process, was used by Wirth in the mobile tunnelling machine that mined about 200 m^3 in a Sudbury mine. It is now used by SMC in the ARM 1100 and has successfully cut over 5 000 m^3 in both the UG2 and Merensky reefs.

This paper defines the work to evaluate cutting processes carried out by Sandvik; the introduction of the machine into a Lonmin Platinum mine; the performance achieved; and the current proposed mining layout for implementation of the ARM 1100 as a mining production tool.

Background

Voest Alpine Bergtechnik is an Austrian Company based in Zeltweg in Austria. They have had extensive experience in rock cutting and for many years they have designed and manufactured road headers and tunnel boring machines. During the late 1990s they, together with Sandvik Tamrock, were major players in the development of the Icutroc process. This development made it possible for pick cutting machines to operate cost-effectively in substantially harder ground.

Initial trials

Towards the end of 1998 developments in the platinum industry were pointing the direction for massive change in the narrow reef mining processes. A number of mechanized mining methods were being evaluated, together with one non-explosive based mining system. Voest Alpine had already applied the Icutroc cutting process in the Stillwater Palladium Mine in Montana, with mixed results. However, the UG2 was regarded as an easier target and it was decided that the most appropriate start was to carry out pick cutting tests, in Austria, on a sample block of UG2 reef.

The reef was sourced from the Anglo Platinum Mine, Union Section, it had a low uniaxial compressive strength of 26 MPa; the sample also contained waste bands of pyroxenite with a UCS of 110 MPa. However, the Cherchar abrasivity index for the chromite ore was 5.4. This is an indication of the extreme abrasivity of the UG2 reef, on a par with high quality quartzite.

The cutting tests were conducted with a variety of carbide cutting tools and at various speeds and depths of cut. The surprising result from the trials was the very low pick life, with the best available picks being severely damaged after only four passes over the UG2 reef. It is believed that the high wear rates were not a function of the uniaxial compressive strength (UCS) of the UG2 but rather the hardness and abrasivity of the chromite crystals that make up the structure of the UG2

Phase II testing

If pick cutting could not provide the answer, it was decided that the practicality of disc cutting should be reviewed. Voest Alpine have participated in various trials of activated cutting, using the Bechem process, and have closely evaluated the oscillating disc cutter currently undergoing trials in Australia. The benefit to be achieved from activating or oscillating disc cutting was considered to be questionable and the technological hurdles to develop effective bearings and seals substantial. It was decided that the most cost-effective option for reef cutting would be conventional disc cutting technology.

A second rock sample was sent to Austria. This was a pyroxenite/norite rock with an UCS of up to 140 MPa, typical of the rock comprising the Merenksy Reef. The samples were cast into a concrete block having dimensions of 4 m × 3 m × 3 m.

Three 300 mm diameter disc cutters were mounted on an ABM 105 roadheader. The configuration of the discs and the cutting action generated a slot 800 mm high and 240 mm deep in the side of the test block. The test machine was extensively instrumented. Analysis of the test results clearly showed that the disc cutting closest to the free face consumed the lowest power, generated the lowest force and created the largest rock particles.

Theory of disc cutting

Mechanical rock failure is a complex process influenced by nearly all rock physical and geological properties. The dominant mode of failure is still a subject of research. One aspect shared by all the theories is the existence of a zone of highly crushed rock material beneath the cutter tip prior to chipping. As the cutter penetrates the rock, a pressure bulb or crushed zone is formed due to the extremely high stresses generated in the rock under the tip of the cutter. The pressure in the crushed zone causes tensile cracks to initiate and propagate into the rock mass. If the stresses developed in the crushed zone are sufficiently high, one or more cracks extend far enough to reach one of the tensile cracks developed from an adjacent cut, or alternatively a free face. In conventional disc cutting, rock failure is in the form of chipping. In undercutting the crack propagation is to a free face and rock fragments generated are substantially larger. Figure 1 shows conventional disc cutting and disc orientation for undercutting

Partnership and high risk items

Up to this stage in the development of the reef miner Sandvik Tamrock and Voest Alpine had worked alone. It was recognized that it was now imperative that they enter into a partnership with a platinum mining company. Presentations were made to the three primary platinum producing companies in South Africa. One of these companies expressed no interest, a second was interested but unwilling to contribute to the cost of the first prototype, and the third company was Lonmin Platinum. They wholeheartedly supported the concept, and Sandvik Tamrock, Voest Alpine and Lonmin Platinum entered into an agreement to develop and trial the Reef Miner. The basic agreement consisted of the following components.

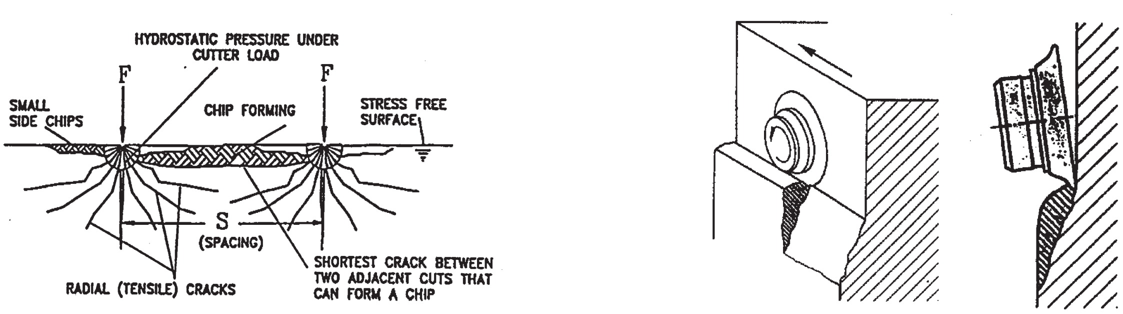

Figure 1. Theoretical rock breaking process for conventional disc cutting and disc orientation for undercutting

- **Narrow reef miner design.** Sandvik Tamrock and Voest Alpine would design the prototype narrow reef miner entirely at their cost. They would own the intellectual property arising from the design of the prototype.
- **Narrow reef miner manufacture.** Lonmin Platinum agreed to fund the cost of manufacturing the prototype. This prototype was manufactured in Zeltweg, tested in a representative manner in a concrete block, modified as and where necessary and shipped to South Africa. The design and manufacture schedule was estimated to be twelve months and the prototype machine was delivered to South Africa in November 2001.
- **High risk elements.** Throughout the discussions between Lonmin Platinum, Voest Alpine and Sandvik Tamrock it has been emphasized that the reef miner makes use of existing technology. The various components of the basic machine concept are all tried and tested. Examples are in Figures 2 and 3.
  However, discussion has identified two high-risk elements, either of which could cause failure of the narrow reef miner to achieve the desired objectives.
- **Cutter life and consequently cutter cost per ton** is the major technological issue. The technology of hard rock cutting is well understood and there is extensive experience of TBMs using disc cutters, with and without carbide inserts. The reef miner uses disc cutters in an undercutting mode of which there is limited experience.
  The feasibility of developing a test rig has been investigated. Such a rig would have to operate in a mine and provide quantitative information on cutter performance. However, such a test rig would have to be as stiff as the prototype machine and have a similar cutting action. In other words, it would have to be substantially the same as the prototype machine. It has been concluded that the limited benefits from such a test did not justify the investment in time or money. The issue of cutter life has been addressed from a more theoretical basis; trials of single cutter discs operating in an undercutting mode have been carried out and use has been made of available design expertise in the practical application of discs operating in an undercutting mode.
- **Mining operations** and the integration of the reef miner into the mine activities. The introduction of technology change on a mine is always difficult and in this project change will affect everyone from senior management to operational staff. The planning of the immediate project will be a trivial issue when compared to the large scale introduction of the Reef Miner. In VAB's experience other mine activities can take up as much as 70% of the available time, limiting the machine operating time to 30% of total time. Good operational controls by the mine will result in substantially increased machine operating time.

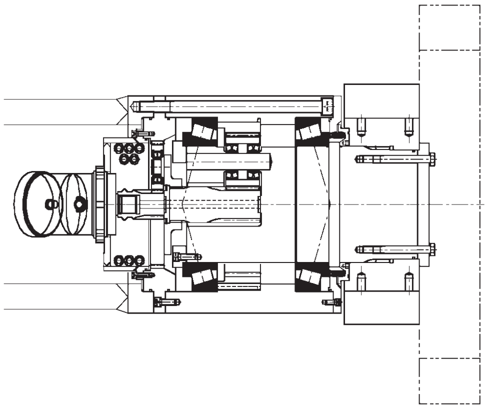

Figure 2. Cutter head gearbox from roadheader

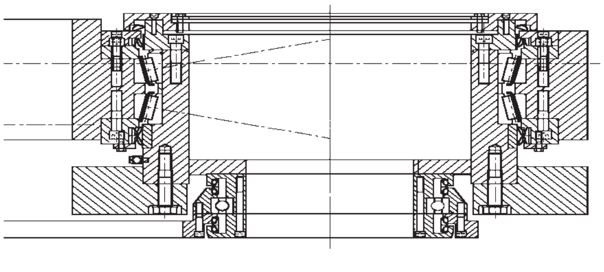

Figure 3. Turret high load bearing from roadheader

Underground trial

Rowland shaft

Figure 4 shows the ARM 1100 test site at Rowland shaft. The cutting trial commenced in January 2002 on 25 Level with the first cut made on February. The first six months of the trial was spent on testing different cutting set-ups and cutter discs and a total of 25 metres was achieved in the period up to July 17. At this point the trial was stopped and new cutters were ordered and modifications to the machine were undertaken. Cutting recommenced in the first week of October and a further 40 metres were cut in the period to the first week in November. By the end of January 2003 the machine had cut a total advance of 100 metres. Each metre cut has a cross-section of 1.1 metres high by 4.25 metres wide and thus a one metre advance is equivalent to cutting just over 4.5 m^3.

The trial team consisted of the following fulltime personnel:

1 Artisan/operator — Western Platinum Mine
2 Technicians — VAB
1 Technician — Sandvik Tamrock

The full-time team had been supplemented by the following personnel:

1 Manager/Engineer — VAB (60% of the time)
1 Technician — Sandvik (80% of the time)

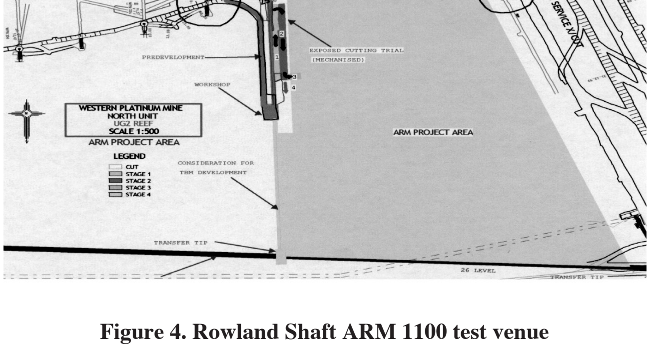

Figure 4. Rowland Shaft ARM 1100 test venue

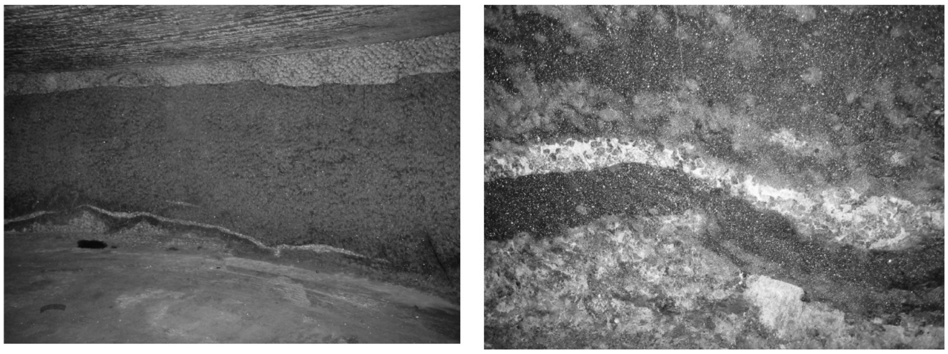

Figure 5. Typical cut face in UG2 and detail of footwall contact

Figure 6. Assembly of the ARM 1100, launching the machine and cutting into the raise

Figure 7. Different carbide profiles tested on the machine

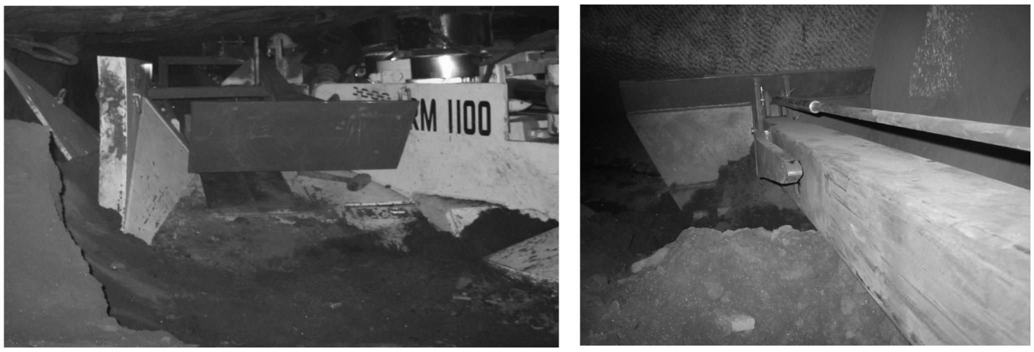

Figure 8. Scoop used to load cut rock onto the belt conveyor

The trial site was well prepared and the level of assistance from Rowland management and personnel was high.

The structure of the orebody at the trial site is reasonably consistent, however, the hardness of the material is relatively high and therefore a good test for the cutting ability of the machine. See Figure 5.

The ARM was installed on the east side of a raise/winze connection and was cutting from the solid face to the free face in the raise. The cutting plan being to cut up dip for a distance of approximately 70 metres and then turn the machine around and cut down dip for 80 metres. Once completed, the ability of the machine to take a blind cut in a strike direction was tested. Figure 6 shows some early pictures of the machine underground.

Cutter configuration

After operating parameters were set, different cutter disc designs were tested. Cutters tested were manufactured with varying angles of attack, different bearing designs and different cutting edges as shown in Figure 7.

After extensive testing of various disc cutters, the best design was selected and it was decided to manufacture according to this design with varying tungsten carbide grades on the inserts.

Cleaning system modifications

During this time the cleaning mechanisms were evaluated and modified to improve the effectiveness of rock removal from the face. Early examples of the different rock removal system are shown in Figure 8.

Machine performance

During the period from start-up to end of July 2002 low daily cutting rates were achieved, week 24 (10 to 16 June) is typical. (Figure 9.)

Following the start-up after modifications at the end of September, advance rates increased to a maximum of 3 metres per shift. This can be seen in the performance charts for week 40 (30 September to 6t October 2002.) (Figure 10.)

This performance improved to 4.57 metres per shift achieved on November 2, 2002, an achievement repeated the following week. (Figure 11.)

Rock cut in this period was UG 2 Reef with a UCS of up to 120 MPa and hangingwall and footwall pyroxenites with UCS of around 140 MPa. The reef in the area dips between 4.5 and 7 degrees.

Findings — ARM Machine

Over 500 cuts have been recorded to date, by means of the on board data-recording system, and evaluated. Information has thus been collected on the following:

- cutter arm slewing force
- cutterhead power consumption
- cutter arm slewing speed and mean penetration
- advance per cut
- number of cutterhead stalls.

This information obtained to date has been used to determine the most suitable cutting geometry and the determination of optimum cutting parameters.

With the cutter arm force set at 230 kN the cutter head does not stall, however, cutter head penetration is limited by depth of cut. Figure 12 is an example of the detailed analysis carried out and shows how penetration and depth of cut are related for different carbide and cutter configurations.

However, the fracture mechanics of the rock breaking process limit the depth of cut that can be achieved. Figure 13 shows effective undercutting in the UG2 at Rowland Shaft with a maximum depth of cut of 50 mm and how undercutting with the current cutter design becomes ineffectual as depth of cut is increased.

Cutter performance

During the trial period 11 different cutter types and two different cutter heads have been tested and evaluated. The cutters tested differed in three basic areas; these are:

- button orientation (15° and 20°)
- shape of buttons/cutting edges (conical buttons, chisel type buttons, steel rings)
- bearing configurations
- angle of cutter axis.

To date 15° conical button cutters have performed the best in terms of wear, performance (performance being defined as cutting rate) and material produced (more chips and fewer fines). Steel ring cutters performed better and produced better material but wore out extremely quickly.

A significant difference in chip size, and consequently

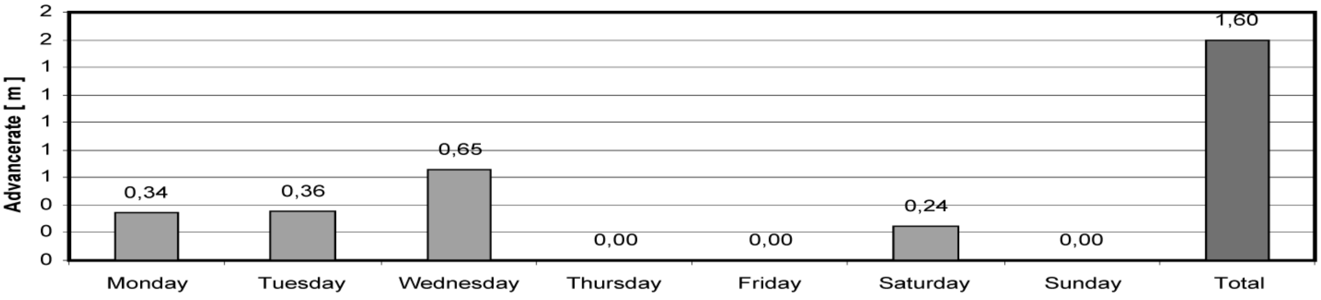

Figure 9. Advanced rate, week 24

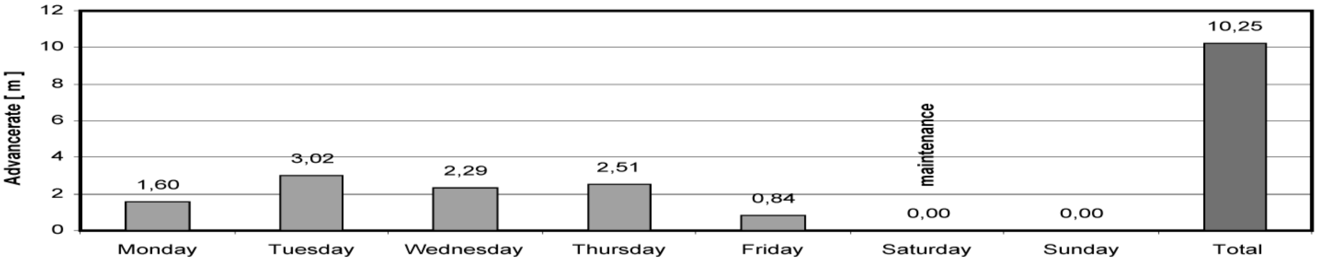

Figure 10. Advanced rate, week 40

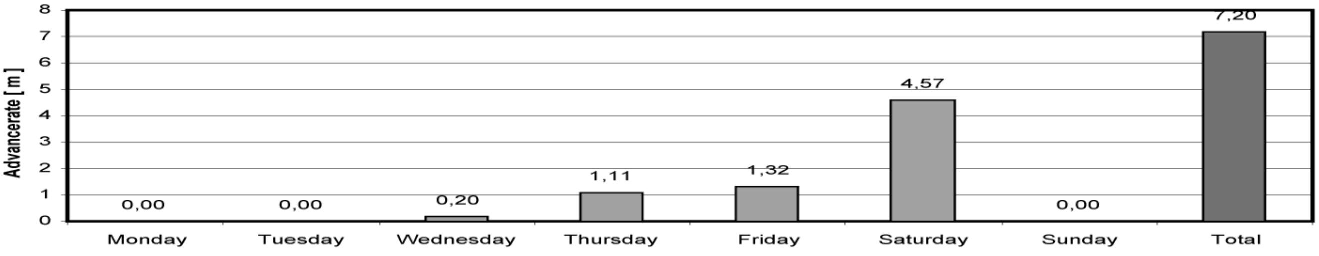

Figure 11. Advance rate, Week 44

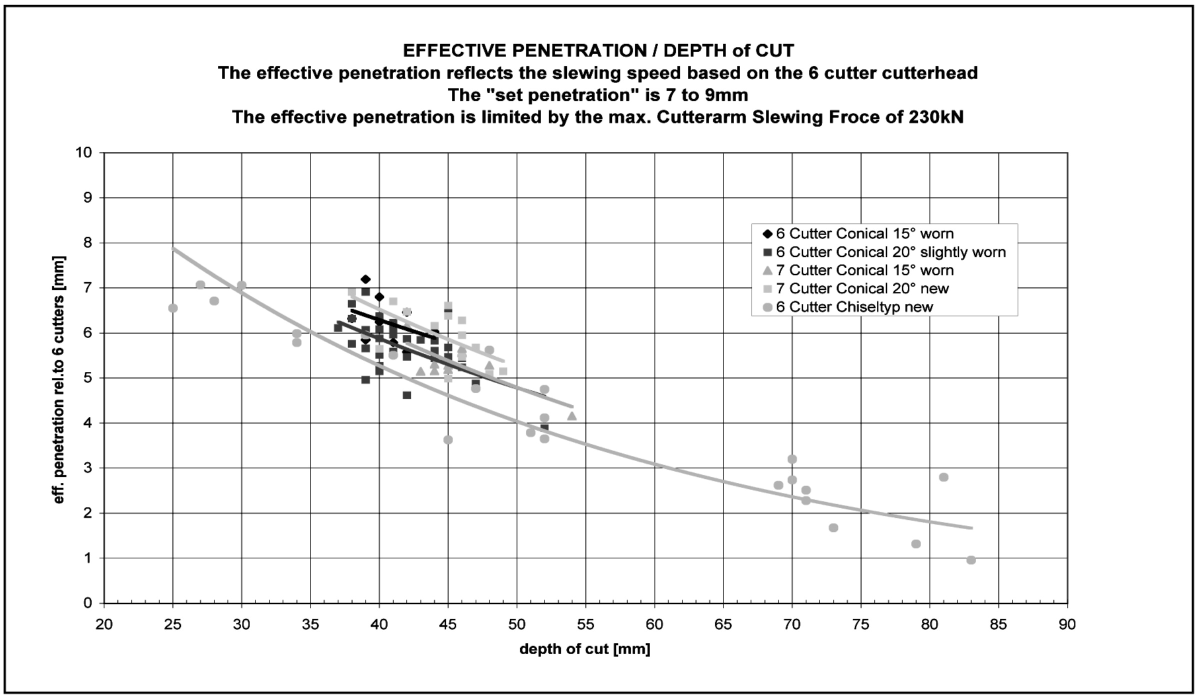

Figure 12. Effective penetration against depth of cut

specific energy, was realized from different cutter types. (Figure 14.)

- The biggest chips and lowest volume of fines were produced with the steel ring cutter.
- The smallest chips and highest volumes of fines were generated by the conical buttons.
- The chisel shaped buttons produced fragmentation sizes somewhere in between the other two cutters.

The first set of 15° conical button cutters lasted 15 metres and could have performed better had it not been for broken buttons, a problem that seems to have been rectified with the latest cutters with the insertion of copper shims in the seat of the button. The latest button cutters have achieved 30 metres with button wear of approximately 30%. Cutter tests aimed at finding the best grade of tungsten carbide for the button inserts have been carried out as shown in Figure 15.

Cutterhead

The original cutter head was designed and manufactured with six cutter discs. It was determined early on in the trial that more cutters on the head will result in a smoother and more effective cutting process. A new cutting head was built and installed in the middle of July and it proved to be a better option with higher slewing speed and greater depths of cuts being achieved.

ARM 1100 development targets

In a development project of this nature it is important to set clear milestones, both from a technological view and from a production performance view. For the ARM 1100 the following different phases or targets were established.

Phase I

The first has been completed and consisted of demonstrating that the ARM 1100 worked. A realistic potential production level was established and preliminary cutter performance determined. The machine can complete an advance of 850 mm in sixty minutes. Carbide rings have demonstrated a life of 30 metres advance with only 5.5 mm of wear.

Phase II

The first part of this phase the project was completed in 2004 and the deliverable at the end of this phase had been determined to be as follows:

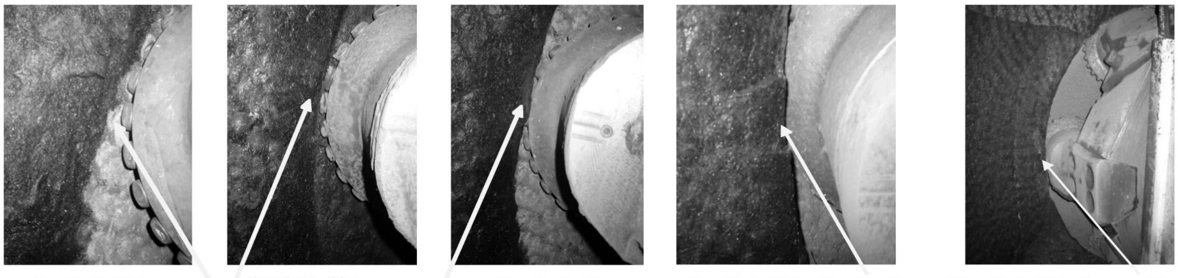

Figure 13. Effective undercutting with varying depth of cut, and with increased depth of cut undercutting ceases

Chips from steelring cutters

Chips from chisel-type cutters

Chips from 20° conical button

Figure 14. Rock fragmentation produced from different cutter configuration

- ARM 1100 performance of achieving a shift advance rate of 3 metres per shift, for 70% of the available shifts for a period of one month. In a twenty-two shift month this equates to a monthly advance of 65 metres. Resolved issues considered to be getting in the way of achieving this objective were:
  - A system of ore handling in the cutting area that would successfully remove +90% of the rock broken per cut
  - A rock handling system to move broken rock from the ARM 1100 machine to the mine rock handling infrastructure
  - Development and integration of a support installation system
- A cutter test programme to demonstrate cutter ring set life equivalent to seventy-five metres and bearing life of two hundred metres. This objective has not been achieved.

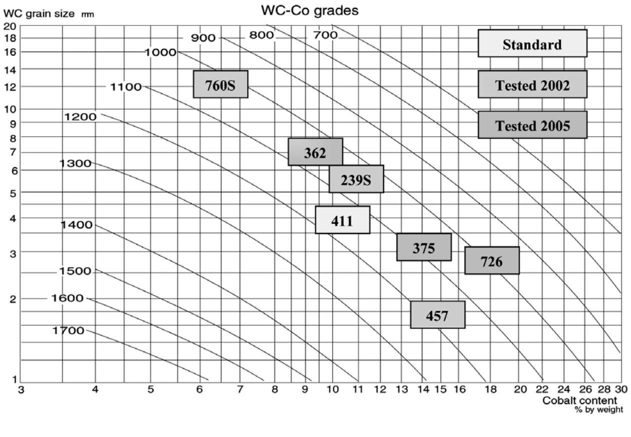

Figure 12. Different TC inserts tested

Phase III

The deliverable at the end of Phase III is greater confidence in the total system performance in terms of production and cutter cost. The specific objectives are as follows:

- Continuous cutting of the ARM 1100 on a two-shift basis for a period of one month. Assuming twenty two days per month and two shifts per day, the advance rate will be 187 metres per month.
- The cutter test programme must demonstrate cutter ring set life of one hundred metres and a bearing life of three hundred metres. This would result in a cutter cost of R56-00 per ton. Demonstration of this objective would require at least 375 metres of cutting.

Production trial 2004–2005

In October 2004, single shift production trials commenced. The aim was to cut 3 m per day for 22 days a month. This would yield a 276 centare production month. Both the October and November trials were successful in yielding 280 centares in 17 shifts. (Figure 16.)

The next target was to achieve a production call of 3 m per shift for 22 shifts on a 2-shift basis. (Figure 17.)

This trial was ended prematurely as the stope ventilation in a blind cut was inadequate. The tipping point was too far for an XLP loader to make the round trips in time, and temperatures in the stope due to the 'blind cut' situation exceeded 36ºC wet bulb.

During this period, extensive cutter load measurements were done on the machine in the actual mining environment. The load measurements were made possible due to advances in memory card technology in recent years. The cutter load measurements revealed the actual loads encountered on the cutters during a cutting cycle as well as making it possible to identify where the loads were generated. 50% of the load on a cutter was used to cut, 40% was used to move ore collecting on the footwall and 10% of

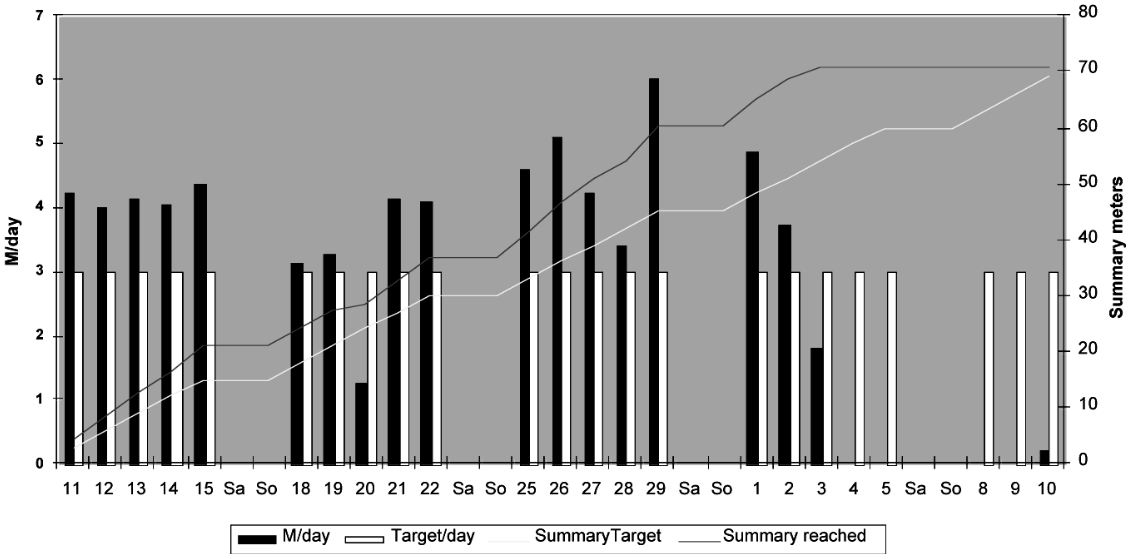

Figure 16. ARM 1100 performance in UG2 in October and November 2004

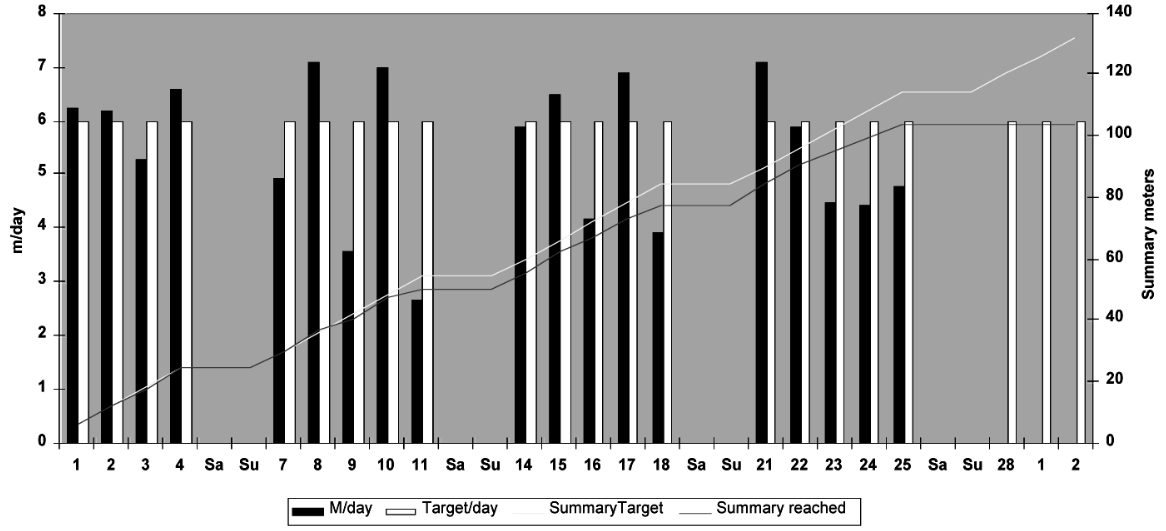

Figure 17. ARM 1100 performance in UG2 in February 2005

the load was caused by the machine kinematics. Resources at this stage were focused on lowering the loads during cutting, as well as increasing the load bearing capabilities of the disc cutter bearings.

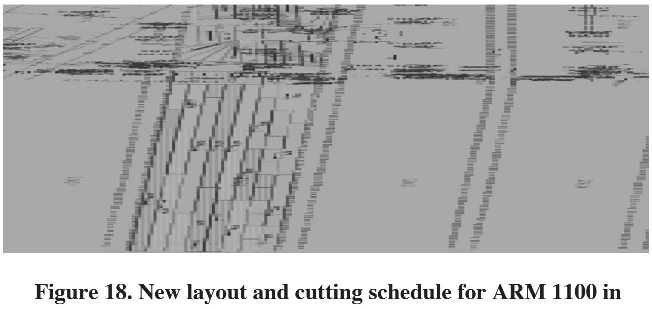

Figure 18. New layout and cutting schedule for ARM 1100 in Merensky at Lonmin

ARM Impala

Cutting commenced at Impala Platinum in February 2004. The decision was made to cut the Merensky Reef at Impala 6#, knowing that Lonmin was already cutting UG2 for the past 2 years. It soon became evident that the Merensky Reef was somewhat easier to cut, due to the brittle nature of the rock. Great leaps were made in increasing bearing life and reducing wear on the TC inserts during the Merensky trials. Cutter cost reached lows of R185/ton, while production rates outperformed UG2 cutting by some 30%.

Moving the Lonmin machine to new ground

Due to proven successes in the Merensky reef and the difficulties experienced with the UG2 mining layout, the joint decision was made to move the machine from the UG2 reef to Merensky. Utilization of the ARM is the key to getting the required production rates, and exceeding them by some margin becomes a possibility.

Performance drivers and the future

Mining layout

The mining layout is essential in achieving production targets. Conventional mining lay outs are altered to produce the highest yield in production. Layout requirements are:

- The section needs to be as long as possible, preferably in a strike direction
- Any blasted areas such as gullys and SPDs would cause a substantial loss in production, due to instability of the machine in these areas
- Tipping points should be no further than 130 m from the machine at any stage in the production process
- Through ventilation in the section would be preferable, but is not a necessity.

The current layout for the machine being installed at Lonmin is shown in Figure 18 and is as follows.

- The machine will cut up and down dip, in a 260 m long, force ventilated stope with only one tipping point at the up-dip side of the stope.
- Ore handling will be done through multiple shuttle cars, handling ore at the machine, transferring it to shuttle cars moving between the machine and the tips.
- Ventilation will be forced up to the machine, where it will be exhausted from the machine to be scrubbed at a remote location further up in the stope.

In short, this mining lay out utilizes the 'half level' layout that Rowland Shaft currently has. There is no need for blasting a gully, as ore is handled via shuttle cars. Ore will still be tipped into conventional box-holes. The shuttle cars will be electrically driven, eliminating any disruption in the mine's current ventilation set up as well as eliminating the use of scraper winches.

Each machine will deliver in excess of 5 000 tons per month with a crew of 7.5 per machine, including supervisory personnel for a multiple machine layout, and 9 crew members for a single machine layout.

Ore handling

For cutting processes able to do their own development, ore handling must be fast, flexible and clean. A lot of time has been spent on refining the ore handling system, using an array of media in trying to achieve the final solution. Using conveyors as an ore handling medium had its restrictions. The possibility of utilizing an extendable conveyor in a 1.1 m height stope, proved to be ineffective. More time was spent moving and extending conveyors, leaving less than desirable production time. Due to the ARM being able to do its own development, conveyors are not able to follow the machine into 'blind cuts', cut away from a tipping point or change direction within the stope. A more flexible system is paramount to the ARM's production output. Currently the machine of choice is the EJC 88 but, due to lack of flexibility and exhaust emissions, further developments are underway. The final solution will be either battery driven or electrically powered with flexibility for bunkering and transport.

Sandvik Mining and Construction is in the process of developing a machine-specific solution for the ARM's ore handling needs. This system will cater for layouts demanding a high level of flexibility and speed. A multiple bucket system is under consideration. Buckets will be able to contain ore generated from two or more consecutive cuts. The bucket will be placed behind the ARM's conveyor. A hydraulic mechanism will move the bucket a set distance after each cut, to ensure that the ore is spread evenly over the length of the bucket so as to prevent spillage. The bucket will then be picked up by a bucket shunting machine and placed on a multiple bucket carrier. Once the bucket is loaded on the carrier, the shunter will place the next bucket behind the conveyor, before the next batch of ore is delivered. The bucket carrier machine will be able to handle three or more buckets, effectively carrying six or more complete cuts (6.5 tons). The bucket carrier machine has a maximum of 9 minutes to dump the three containers at the tip and return back to the machine. While the bucket carrier is away, the bucket shunter will place the filled buckets on the footwall. With 9 or more buckets in circulation, temporary bunkering of ore will be possible, ensuring no interruption in production of the ARM. (See Figure 19.)

In applicable future mining layouts, it will be possible to re-employ the scraper winch as the primary ore handling system due to its simplicity, cost and flexibility. The system will require the stope to be re aligned with tipping points, to ensure that the scraper winch will be pulling ore up to the tip alongside the section pillar. Due to the profile of the ARM's cut, the scraper winch will run on the footwall, eliminating the need for the normally associated gully profile. An LHD will be used to collect the ore from the back of the ARM conveyor. The ore will then be tipped in the path of the continuously running scraper winch. With the needed access restrictions in the section, the winch can be fully automated as well as the LHD. Cyclic use of adjacent sections will allow the support of a 4 m effective face advance to be delayed. Bolting of the previous cut will commence once the ARM is cutting in an adjacent section. This will eliminate the need for an on-board bolter, replacing 3 bolters with one. No operators will be needed at the machine while cutting is in operation, thereby achieving fully remote operation.

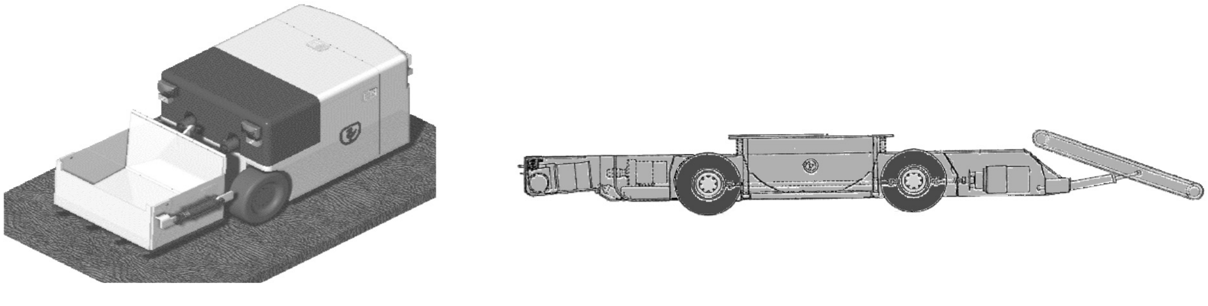

Figure 19. Possible new ore handling systems to complement the ARM 1100

Comment

Optimizing production

Today, the ARM can produce a production figure of 4.2 m^3/hour. By optimizing the mining layout to keep the ARM continuously cutting, utilization figures of 75% can be sustainably achieved. Utilizing 24 hours per day, production levels of 1 900 centares per month will be possible. Only further development of the machine and disc cutters is needed to increase this figure continuously.

Optimizing mining cost

The total labour cost portion of the ARM system totals 12% at full production. Only 7.5 crew members are needed to produce 7 000 tons per month. ARM cutter cost comprises 55% of the total Mining cost at full production. This would mean that mining cost can now be driven by advances in cutter technology rather than labour cost and its associated effects.

Optimizing ore reserve dilution

Although difficult to quantify, the gains to be made with a stoping system that self-develops is real. Based on current mining layouts for Lonmin, the total development needed per 1 000 m^2 of stoping, is in the order of 12.5 m. This figure includes haulage, workshop, box hole and slusher development. Through developing haulages on reef, this figure will dilute to 5.5 m/1 000 m^2.

Optimizing ore reserves

Due to the safe and non-destructive mining action of the ARM, ore reserves previously known as 'not suitable to mine due to ground conditions' can now be added to the ore reserve capacity. This will have an adverse effect on the lifetime expectancy of ore reserves.

Conclusion

The move to rock cutting and continuous mining is seen as the ultimate objective for many underground hard rock mining practitioners. The challenge is to develop a working machine, followed by a cost-effective mining system. Sandvik Lonmin and Impala are very close to achieving this objective after a number of years' work. Total cutting in South African platinum mines exceeds 7 200 m^3 and there is additional experience from cutting in a Polish copper mine.

Placer Dome has also developed a narrow reef hard rock mining machine at a cost of some $20 million. The machine has operated in an underground stope and cut some hundreds of cubic metres.

The activated disc cutter machine developed by the CSIR, Anglo Platinum and Long Airdox has cut a few cubic metres in a narrow stope.

The oscillating disc cutter is seen by some as the possible basis for a hard rock cutting machine. To date experience is limited to laboratory trials and limited cutting in a quarry.