Shotcrete lining of South Deep shafts

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Synopsis

This paper will focus on the use of the 'wet-mix' steel fibre re-inforced shotcrete as a permanent lining in deep shafts, assessing gold bearing reef. It will cover all aspects relating to the choice of this material covering the geological conditions through to the final quality control. All procedures are in line with ISO 9001, as JCI projects who manage the project, are an approved company therof.

Introduction to the South Deep Shaft

South Deep, which is a gold mining operation controlled by the Placer Dome Western Areas Joint Venture, is situated about 50 km west of Johannesburg and 20 km south of Randfontein in typical Gauteng Highveld country. It is the largest single gold deposit known in the world. The orebody is complex and dips north/south at ± 18 degrees between 2500 m and 3500 m below surface. The thickness of the orebody varies from 1 m to 90 m and has a planned life of mine in excess of 60 years at 220 000 reef tons per month.

The mine occupies a lease area of approximately 1 481 ha. The northern portion of the mine's lease area comprises a gently northward sloping dolomite plain containing depressions typical of karst type topography. Southward, two prominent ridges separated by a dolomite inlier provided a suitable site for the mine's surface shaft (South shaft) with its associated infrastructure. Kloof, Libanon, Venterspost and Randfontein Estates Gold Mines at its western and northern extremities bound the mine, respectively. Figure 1 shows the position of the mine relative to surface infrastructure and neighbouring mines.

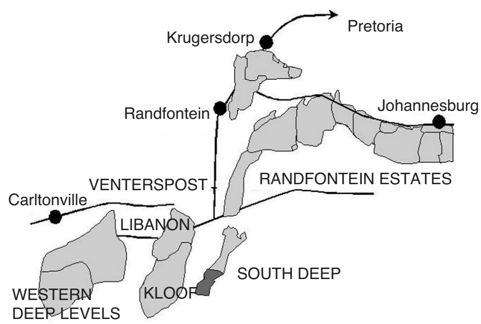

Figure 1—Location of South Deep twin shafts

Background to the South Deep shaft sinking project

The South Deep shafts were positioned to pass through the single reef (VCR) orebody for practical, economic and several other advantageous reasons which have been covered in a number of previous papers.

The location necessitated a philosophy of shaft pillar protection. This protection was based on pre-extraction of the reef together with extensive backfilling of the shaft pillar area, prior to the sinking shafts intersecting the VCR plane. The practice of shaft pillar pre-extraction is nothing new in the mining industry and is the preferred method of ensuring the long-term stability of a shaft.

The application however, of a suitably designed shotcrete system in an area above and below the pre-extracted reef plane, including an instrumentation monitoring program, is something new to the industry.

This aspect will be covered in some detail in this paper.

Rock engineering reasons for permanent shotcrete lining

From the outset, the option of siting the shafts in unpay or sterile areas was not viable, as this would have had the effect of removing the shafts from the centre of gravity of the orebody, with consequently excessive lengths

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of development. The proximity of the South Shaft complex to the South Deep shafts allowed for the orebody, between 90 and 95 levels, to be pre-developed. This fact allowed for the shaft reef intersection area of the South Deep shaft complex to be pre-extracted and backfilled, thereby eliminating the requirement for a shaft pillar, whilst placing the twin shafts close to the centre of gravity of the orebody.

Shaft reef area pre-extraction has several benefits:

- ➤ It enables early gold production for the mine, a conventional solid shaft pillar would have locked up ore reserves over an area of a square kilometre
- ➤ Avoids the problems of mining a highly stressed shaft pillar later in the mines' life
- ➤ Allows for the training of a nucleus of management and skilled employees in the deep level environment, prior to full production capacity being available
- ➤ Pre-development for the first decade's mining reserve, allowing a rapid buildup of production, once the shaft system is commissioned.

The use of a high performance crushed waste/classified tailings (CW/CCT) backfill, was dictated by the need to limit stress and strain changes in the shaft barrel, over a projected sixty-year life of the shaft system. Another requirement, which led to the choice of this backfill type, was the need to limit the potential for seismic activity in the vicinity of the shafts. Energy Release Rate (ERR) on mining faces and the Excess Shear Stress (ESS) on major fault planes, both of which are measures of seismic potential, were calculated using numerical models and were found to be significantly lower with CLCW/CCT backfill as compared with CLCCT backfill.

In order to confirm that the input parameters and modelling procedures used for the prediction of potential shaft damage were correct, it was necessary to carry out *in situ* instrumentation and modelling back analysis exercises, on the actual VCR stoping configurations. Underground instrumentation sites were established to measure the closure in the gullies, as well as the stress and closure in the placed backfill. The *in situ* results obtained, were compared to the numerical modelling results, to confirm that the model-input parameters were correct. Additional confirmations of the elastic parameters were also obtained, by measuring the deformation of footwall excavations in response to overstoping on the VCR. The correlation of these results confirmed the far field rockmass behaviour. Because of this, a high degree of confidence could thus be placed in the modelling results and hence in the predicted future shaft deformations.

Since the VCR stoping around the shaft area will be continuing for a period of at least 15 years after the shafts are sunk, allowance must be made in the support of the shaft sidewalls for a constant change in the overall stress and strain environment. A strain criterion of ±0.2 mm/m was used for the analysis of the stability of a 300 mm monolithic concrete lining placed in the barrels of the twin shafts. Areas along the length of the barrels exceeding this criterion, were determined by elastic boundary element modelling. Three-dimensional Fast Lagrangian Analysis of Continua (FLAC3D) modelling incorporating non-linear rockmass behaviour was also conducted, to verify the response of a concrete lining, to strains in excess of the design criterion. A monolithic concrete lining will be subjected to radial tensile stresses in

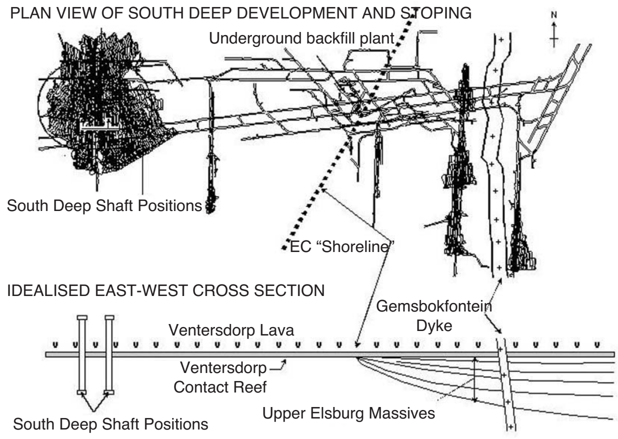

Figure 2—Geological map

excess of 8 MPa, over the life of the shafts. The cast concrete can be expected to withstand tensile stresses of up to 3 MPa before the onset of cracking. Based on this reasoning, it was decided to apply a fibre-reinforced shotcrete lining, to areas of the shafts where strain changes in excess of the ±0.2 mm/m were predicted. Fibre reinforced shotcrete has a significantly higher ductility than monolithic concrete and will thus be able to tolerate the high strain changes. Based on both the results from the elastic boundary element modelling and elastic/inelastic FLAC3D modelling, a team decision was made to support a 352 m length of the shaft barrel with fibre reinforced shotcrete (FRS).

Advantages of wet steel-fibre reinforced shotcrete

Six months before shotcreting was due to begin on-mine, a working group was set up. This group comprised persons from JCI Projects South Deep, as well as the main contractor, specialists in concrete technology, additive and equipment supply specialists, a quality assurance company experienced in mining, rock engineering personnel and aggregate suppliers.

This group discussed and debated all aspects of the shotcrete (including the possibility of dry shotcrete) until a consensus was reached on the complete system. This way there was a 'buy-in' from all parties concerned, long before actual shotcreting took place in the shaft.

It was agreed that wet shotcrete would be the only option for a number of reasons:

- High strength (controlled water/cement ratio)
- High energy absorption (Ductility/Toughness)
- High density
- Low permeability
- Increased ductility of base mix
- Low shrinkage
- High bond
- Durability of re-inforcement
- Stability and durability
- Pumpable and sprayable
- Appliable in wet conditions
- Verylow rebound
- Early strength and support
- Consistent quality

Dry versus wet shotcrete comparison	
Dry shotcrete	**Wet shotcrete**
Advantages	**Advantages**
Equipment relatively inexpensive Equipment relatively small and very mobile Can be used in confined spaces Pre-bagged material, usually 25 kg, easily manually handled In-place strength (compressive) may be high Can be used for small volumes	Rebound is very low, 5% on walls and 10% overhead No laminated layers of dust Consistent quality due to mechanical batch mixing C/W ratio consistent in a batch and strengths predictable No wastage of material during mixing Accelerator is liquid and feeding rates are easily controlled Output rates normally high, 10 to 20m^3 per hour Wear and tear low due to wet material being less abrasive Dust levels are very low Requires less compressed air Can use stabilizers to enable use over long periods (3 days) In-place costs may be lower **Quality can be predicted with confidence**
Disadvantages	**Disadvantages**
Rebound is high ± 30% on walls and ± 50% overhead Consistent quality not easily obtained as nozzleman regulates water feed. ***In situ* quality cannot be predicted.** Homogeneous mixing of material not ensured as it is done manually Mixing of materials is normally done on the ground leading to much wastage Dosage of powder accelerator is not easily controlled Output is very low Wear and tear on feeder plate is high Dust levels are very high Pockets of rebound material can be sprayed over creating weak zones or laminated layers Requires high volumes of compressed air. **In-place costs may be high**	Equipment relatively expensive Generally equipment more and larger Wet shotcrete is heavy and makes hoses difficult to handle Not cost effective to do small quantities at a time.

Design/specification

Design parameters assessed included 'early age' and long-term compressive strength, *in situ* strength, energy absorption capabilities and yieldability. The application of a factor of safety (FOS) of 1.7 to the modelled horizontal compressive strength was used to determine the design compressive strength of 60 MPa for shotcrete. In addition, the placed shotcrete had to be sufficiently impermeable to ensure long-term durability of the fibre and concrete matrix. Using the European Federation of National Associations of Specialist Contractors and Material suppliers for the Construction Industry (EFNARC, 1993) specifications, the energy absorption criterion was set at 1000 J for a 28-day plate test. Sporadic incidences of strain bursting of shaft sidewalls resulted in an 'early age' strength of at least 5.0 MPa after 48 hours and the ability to absorb 400 J of energy after 4 to 8 hours being adopted. A program of testing incorporating various combinations of shotcrete ingredients commenced on October 1998. The EFNARC, 1993 specifications of sprayed concrete was used for all shotcrete tests conducted. Based on the results of these tests, the Dramix 40 mm long austenitic stainless steel fibre was chosen as the shotcrete-reinforcing ingredient that would provide the required ductility, when combined with the chosen admixtures, aggregates, cement and water.

SFRS mix design details

The mix finally adopted was a complex blend of very high quality materials with each constituent being included for a very specific reason.

The various mix proportions were constantly monitored and revised as the work progressed and conditions changed.

The constituents were:

- **CEM 1 52,5 cement**—A very basic constituent but of great importance and necessity to create high early and final strength in a cost-effective manner. Lafarge South Africa cement was used.
- **Superfine fly ash (Superpoz)**— added to reduce water demand, assist pumpability, increase resistance to chemical attack and provide long-term strength gain. Supplied by Sphere-Fil through CLP
- **Quartzitic**—aggregates of a specific quality and consistent grading within narrow limits supplied by CLP.
- **Delvocrete**—Hydration Control Admixture—to create long 'open' time, to assist in fibres dispersion during mixing and to facilitate flexibility in placing. Very high quality material supplied by MBT.
- **MEYCO TCC 735**—an internal curing agent and concrete improver—very useful product especially with crushed aggregates and pumped mixes, supplied by MBT.
- **Stainless steel fibres**—Austenitic, very high tensile strength and of high corrosion resistance. Supplied by Bekaert, through local agent (CRF).
- **Fibrin 23 microfilament polypropylene fibres**— although used at very small dosage these were an extremely important element of the mix; they were of very high quality, supplied by Adfil through Chryso locally.
- **MEYCO SA 160 accelerator**—A non-deleterious accelerator, first time used in South Africa, a totally key component to create high early strength and continued long-term stability. Supplied by MBT.

Mixing of product

As the majority of the material would be placed in the shaft barrel, or on the periphery, it was decided to use the mixer at the main shaft. A second mixer was set up for the vent shaft, a few months after commencement of shotcreting. This was the preferred option to transferring the mix from the main shaft to the vent shaft by conveyor or rail-mounted kibble.

It was necessary to upgrade/maintain the mixer, as well as accurately calibrate all the scales, water meters, etc., so as to ensure precise dosage of cement and water addition into the mix. As a pre-bagged aggregate (including silica fume) was used, it was not necessary to improve the accuracy on the aggregate scales.

Additives were pumped up to the mixing platform to small holding tanks and then dispensed by hand into the mixer. Fibres were introduced into the mix, using a locally manufactured rotating cone type feeder, from pre-packed containers of 20 kg each.

Each mix was 0.5 m^3 and the mixing time was strictly monitored, in order to get the maximum benefit of the admixtures and ensure complete dispersion of the fibres in the matrix.

Logistics

Two options were considered for transporting the material down the shaft. In both cases however, a conveyor would be used to receive the shotcrete from the mixer.

Slick-line

Slick-lines have been extensively used to handle shotcrete with fibres around the world and in South Africa. However, it was decided not to use the slick-line, as it was worn and the very long length of pipe would need an excessive amount of flushing and cleaning, in relation to the volume of material used per 3 m lift. In addition, using the slick-line would not guarantee that the water/cement ratio of the shotcrete would remain constant, due to the amount of free water in the shaft.

After all these factors were considered, the final material system was implemented as follows.

- ➤ Dry constituents were pre-bagged in bulk bags of 0,5 m^3 (produced) volume. This was done off-site at the CLP facility at a nearby mine, which is SABS accredited. Thus, very careful control was achieved 'upfront'. Special bottom opening bags were created for easy discharge and materials within the bags were weather proofed. Factory conditions ensured consistency. Bags were transported to site as required, to keep a reasonable stock on-site at all times.
- ➤ The bags were off-loaded into a special storage area near the batching plant.
- ➤ When needed, individual bags were loaded into a weather-proofed bin, where contents were emptied and loaded into the mixing pan by a dedicated and specially constructed conveyor. Thus, minimal weighing of materials was required at the batching plant and consistency was assured. Cement was added via accurate weigh-scales.
- ➤ The required volume of water was added along with pre-measured volumes of additives (hydration control, super plasticizer and internal curing).
- ➤ Steel fibre was added during this process by a specially constructed fibre dispenser (designed and supplied by CLP).
- ➤ Finally, Fibrin 23 polypropylene fibre was added by hand, in pre-weighed amounts.
  Thus, all constituents, except cement and water, were pre-measured. This again, helped to create a level of consistency.
  After mixing, the consistency was checked by flow-table and adjusted (if necessary) until the correct flow was achieved. This therefore controlled the total water content.

At correct flow, the SFRS was discharged and transported as follows.

- ➤ The material dropped onto a conveyor, which transported it up and into a specially adapted kibble.
- ➤ The kibble was an unique feature. It had been specially adapted with a discharge facility controlled by a valve and had a water-proofed covering, due to very wet conditions in the shaft.
- ➤ After filling with 5 batches (2,5 m^3), the kibble was transported to the shaft, coupled and lowered into the shaft, down to the shaft bottom.
- ➤ It was suspended just above the MBT pump, again which had been rain-proofed to avoid dilution of the mix.
- ➤ The positioning of the pump was an unique feature. It was adapted to be transported into the shaft only when required, normally being kept on surface.
- ➤ SFRS was discharged into the pump hopper and pumped to the nozzle, which of course was close to the sidewall.
- ➤ Compressed air and SA 160 accelerator were added at the nozzle and material 'shot' onto the sidewall.
- ➤ The use of a very high quality accelerator is worth noting. This was SA 160 supplied by MBT and was of the alkali-free type. It was used because :
  - *Safety—it was much less hazardous (other accelerators DO cause health problems)*
  - *No loss of strength was incurred (other accelerators DO cause significant strength loss)*
- ➤ It is also important to note that the operators, particularly the nozzle man, had been trained by MBT and made fully aware of the correct technique.
- ➤ During spraying, which was done in very wet conditions, constant checks were made to ensure correct thickness and full application. This was done by the use of an unique feature. A metal, pointed probe, with a large washer fixed at the appropriate point at a distance from the tip, was used (because of its appearance it was called the 'ski-stick').
- ➤ By using this probe, it was quick and visually apparent, if the correct thickness had been achieved but no penetration being possible further than the fresh SFRS. If the correct thickness was in-place, an impression of the washer was made, and this remained upon hardening. Thus, a visual record of minimum thickness, was a permanent feature.
- ➤ It is also important to record, that the sidewalls were

subject to running water and the mix had been specifically designed to prevent washout. The use of the SA 160 was of great importance here, as was the stickiness of the mix, coupled with the Fibrin fibres, which aided build up.

- Re-bound was very low—probably in the region of 3% (accurate measurement was not possible due to the wet conditions).
- Fibre re-bound was also low.
- Test panels were sprayed during each operation, as part of the planned quality assurance programme.
- Such panels are often badly damaged during transport to surface and will thus give false results in testing. To prevent this, a specially constructed cage was used, to protect panels during transport—again a unique feature.
- During the course of the works, **all** materials used and areas sprayed (with calculated volumes) were constantly reconciled. Thus, in addition to the in-built and on-going 'hands-on' quality control, an additional check was available to ensure in-place quality and thickness.
- In addition to the cube samples taken at the batching plant, test panels were cored to check *in-situ* compressive strength, or tested for energy absorption.
- Results were plotted and presented graphically. These were evaluated and discussed on a very regular basis, with actions taken if appropriate. An example of the process is shown in Figure 4 and 5, where it will be seen that mean Energy Absorption (the most important characteristic) is well placed above the minimum requirement.
- A very important safety issue was that the application of the SFRS to the sidewall on the shaft bottom, meant that personnel were then protected from falling sidewall, during future sinking operations.

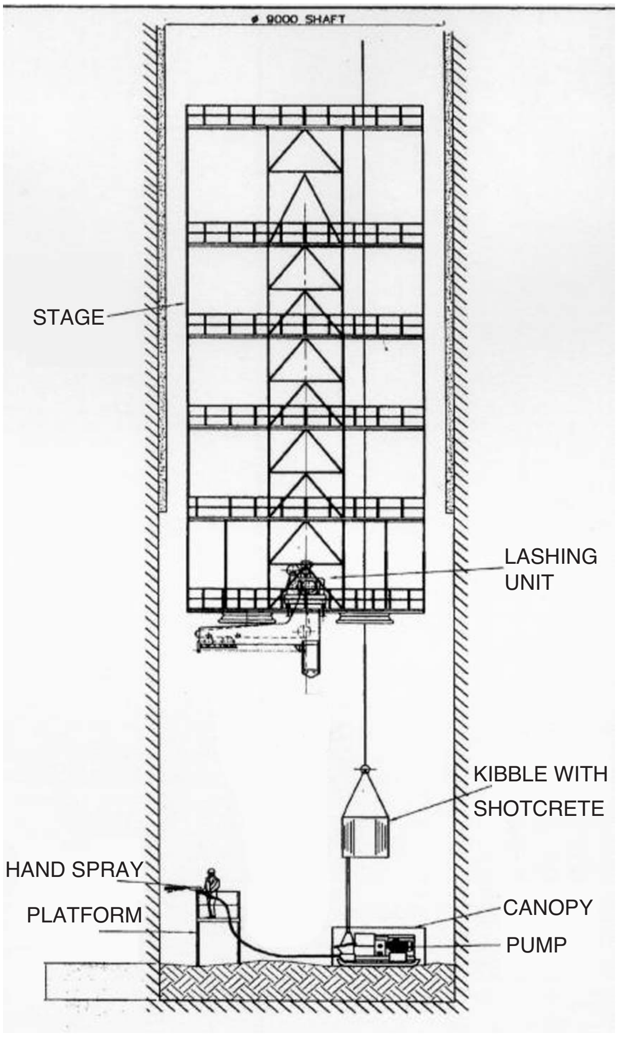

Figure 3—Actual spraying method

South Deep trials

To ensure that the applied material met with the required specification, South Deep undertook an extensive series of tests.

These tests were done well before actual shotcreting was due to start in the shaft. The early start, allowed for the 28-day energy absorption panel results to be available so that the performance characteristics of the first material applied would be known.

A very large number of EFNARC panels were sprayed on surface, with the objective of obtaining a matrix of data, comparing the following parameters:

- **Fibre type** — High-tensile steel; High-tensile stainless steel and polypropylene fibres
- **Shotcrete thickness** — Different thicknesses from 50 mm to 130 mm were sprayed
- **Different ages** — Tests were done on panels and cubes from 2 days to 56 days.

In all cases, the basic concrete mix design was kept constant, so as to focus on the criteria being compared i.e. fibre type, thickness, etc.

This extensive series of trials more than justified the cost for a number of reasons. The main ones being:

- There was a confidence build-up in the quality of the materials, so that the first shotcrete applied was very close to the required specification.
- The surface spraying over a number of weeks, allowed an extended training period, using the actual equipment and materials onsite. This gave the operators a confidence in the new process, which was relatively easy to transfer to the real situation in the shaft.

Training

As the wet mix process was new to the contractor, it was vital that the applicators were trained by specialists. It was also necessary to train the Quality Assurance staff, in order that they had the necessary 'know-how' to monitor the applicators.

A comprehensive programme was provided by MBT for both supervisors and operatives. The training course was divided into two parts:

- **Theoretical,** and
- **Practical**

Theoretical

The theoretical part was modified for the supervisors to cover more on concrete technology. Aspects covered in the theoretical part of the course included:
- Definition of shotcrete
- Basic mix designs and the importance of the materials including admixtures
- The principle of wet shotcrete and the difference vs. dry shotcrete
- The advantages and reasons why wet shotcrete is used
- The reason why steel fibre is used and the importance of achieving low rebound.

Practical

Aspects covered in the practical part of the course included:
- Pump start-up and equipment check list
- Spraying techniques
- Cleaning checklist
- Trouble-shooting (both equipment and shotcrete)
- Safety and Environment were key aspects overall.

At the end of the course, candidates wrote a test and were given certificates. During the course of the project, MBT provided on-site underground audits and on-going training. Training at all levels on wet shotcrete is an essential part of the success or failure of the system.

Quality Control

Owing to the sixty-year life expectancy of the mine, some very poor ground conditions and at times high volumes of sub-surface water, it was imperative that only materials and workmanship of the very highest standards were incorporated in the manufacture and application of the shaft lining material.

To achieve this control, the first requirement was, to produce a working procedure for the manufacture and application (an ISO 9000 requirement). As no similar document existed in the industry it was necessary to write it from scratch.

The Working Procedure was written by South Deep, however, considerable input was also received from the following:
- AATS
- Cementation Mining
- Geopractica
- MBT Mining
- CLP.

The document (some 32 pages long), covered all activities, from procurement of materials through to summarized Quality Control forms. This procedure was constantly updated, as activities were changed to improve the process.

The second requirement was a 'Tailor-made' Quality Assurance and Quality Control system, to encompass the whole process. Geopractica developed both systems.

The Quality Assurance plan encompassed materials, mixing, plant and equipment, as well as substrate preparation. The Quality Control scheme was structured to report on individual tests, as well as to highlight early, any undesirable trends so that quick action could be taken to rectify them. A full statistical analysis of the 7, 28, and 56-day results was provided for both shafts, as well as the EFNARC panel test results for each shotcreting operation. From this information, it was possible to locate any problem area in the shaft and make informed decisions, should action/rectification be necessary.

The testing frequency determined for this project is indicated below:

Description of Test	Frequency
Compressive strength determined from cubes	6 Cubes (two individual tests) per 20 m^3 of shotcrete manufactured
Compressive strength determined from cores	6 Cores (two individual tests) per spraying event
Energy absorption values	1 Panel per spraying event
Flow tests	Every batch manufactured

South Deep sinking shafts—interesting facts

Quality Control testing

- 970 EFNARC panels were tested, a total mass of ± 145.5 tons or ± 65m^3
- 6682 cubes were manufactured and tested, a total mass of ± 14.7 tons or ± 7m^3
- 5534 cores were tested, a total mass of 11.5 tons or ± 5m^3

Approximate material usage

A total of ± 7522 m^3 of shotcrete was manufactured comprising:
- 11 298 tons of aggregate
- 3 707 tons of cement
- 286 tons of condensed silica fume
- 564 tons of Superpozz fill
- 29 275 litres of stabiliser
- 30 353 litres of superplasticizer
- 51 855 litres of hydration controller
- 174 924 litres of accelerator
- 6,870 tons of polyfibre (Fibrin)
- 160 tons of mild steel fibre
- 183 tons of stainless steel fibre.

Safety Benefit

The ventilation shaft was sunk to its final depth of 2790 metres below collar, or 1192 metres below sea level, making it the deepest shaft ever to be sunk without a single fatal accident. This achievement has been attained over a period of 5½ years or 1960 days, working 571 245 man day shifts.

During the sinking phase, shotcrete lining of the shaft started at a depth of 2345 metres below collar, to the final depth of 2790 metres below collar. This area of the shaft traversed the reef horison, where the shaft pillar was extracted. During the planning phase (numerical modelling), the shaft lining requirements were based on vertical and horizontal strain deformation criteria. It was recommended, that the concrete lining be replaced by a high quality fibre reinforced shotcrete lining, where residual strains in excess of ±0,2 mm/m are expected.

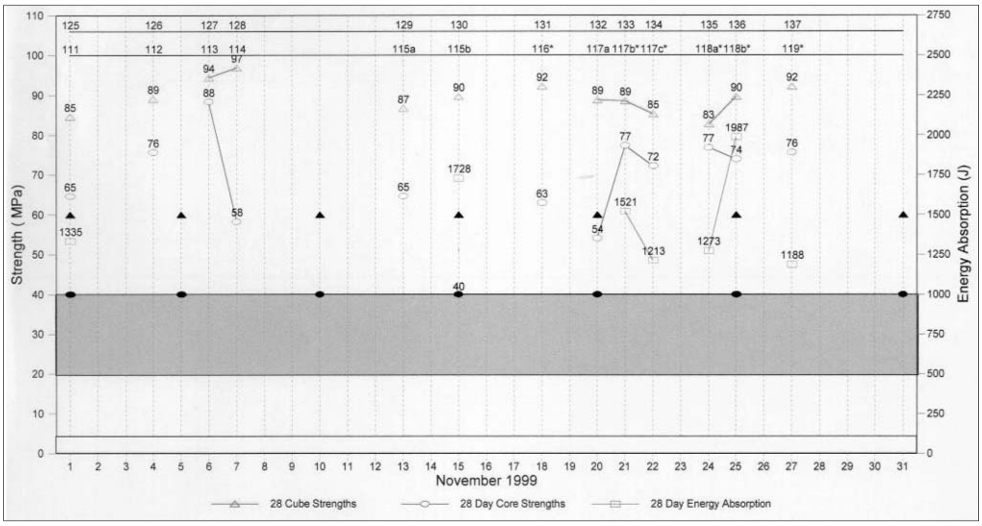

Figure 4—South Deep, main shaft: Underground production spraying

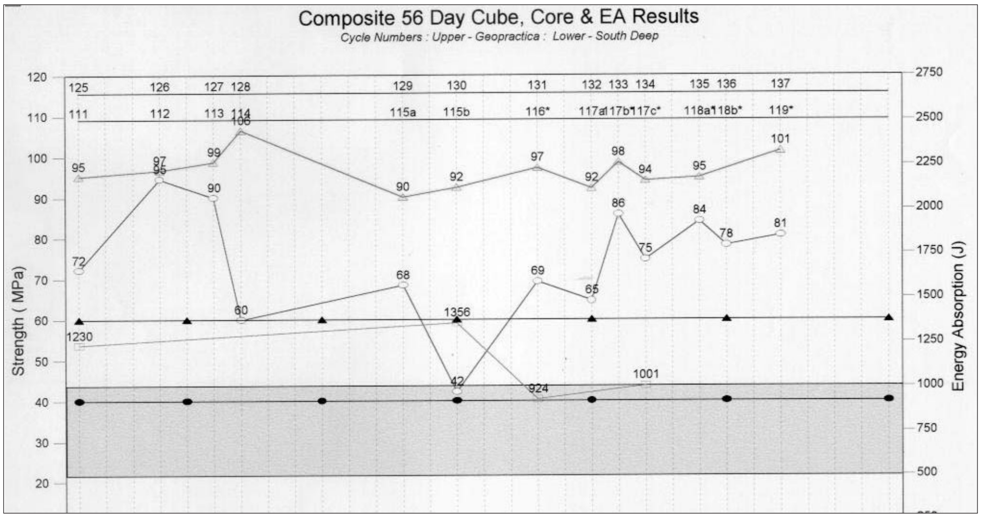

Figure 5—Main Shaft: Underground production spraying

Fibre reinforced shotcrete is generally stronger and capable of greater plastic deformation than concrete lining (James, De Maar, Prof. Wagner and Dr. Esterhuizen). As it is applied perpendicular to shaft sidewalls, its compactness is excellent in the direction required to resist horizontal as well as vertical strain. A thin layer of shotcrete is applied, compared to concrete lining, therefore any damage is relatively easy to repair.

The rock engineers, using numerical models, indicated a three-dimensional movement in the shaft barrel over a total length of 490 m of the shaft between 2260 m to 2750 m (originally planned), will require a fibre reinforced shotcrete lining. The benefits of the SFRS applied cannot be over-emphasized, as this made a positive contribution to sustain the rock mass and prevent scaling of rock, avoiding injury to persons. The blasted rock was lashed/mucked out and the SFRS applied to the shaft sidewall, covering all exposed rock (excluding the shaft footwall).

Furthermore, the excellent safety performance can also be attributed to well-developed safety standards, enforced by regular risk assessments, safety meetings, motivational talks and training of personnel. Re-training of persons was a major contributory factor to the safety rate achieved. A culture of zero tolerance to non-conformance has developed amongst the team.

A notable extra safety benefit was realised from the SFRS after the shaft sinking had progressed beyond the de-stressed zone. A request came from the sinking crew to use the SFRS as the temporary support (i.e. replace the steel mesh and bolts with a 50 mm layer of shotcrete and bolts). Such was the confidence in the safety benefits of the shotcrete, it was decided to adopt this procedure, despite the higher material cost and increase in cycle time. The fact that there were no ‘fall of ground’ injuries while SFRS was being applied, justified its use in this case!

Cost

The cost of the shotcrete material using stainless steel fibre amounts to R2 897,23/m^3 ,whilst the cost of mild steel fibre amounts to R1 496,53/m^3. (In 2000 financial terms).

Lateral development end sidewalls, as well as the hangingwalls, were covered with a layer of SFRS. Thickness of the applied shotcrete varied depending on the ground conditions. However, a reduction of mild steelfibre was recommended and the overall costs were reduced to R1 416,65/m^3. Although the time to lower equipment i.e. Corretta pump, accelerator material, spraying the shaft sidewall (±95m^2 off), removal of the equipment to surface consumed about 2 hours of the blast-to-blast cycle time. The benefits of a safe and secured sidewall, the added benefit of not having to spend time in barring the sidewall after each blast and possibly again during the lashing cycle, is a major tribute to SFRS. The shaft sidewall having the SFRS. as a permanent means of support, with no concrete lining to follow, i.e. lowering of the curb ring, shutter, etc., further compliments the feasibility of SFRS.

Conclusions

The use of SFRS. in the particular application for the reasons as discussed through the paper, has by all accounts exceeded expectations, in terms of compressive strengths and impact energy values achieved from the results of *in situ* tests of material placed. This no doubt, must be credited to the diligence applied to the development of the design, standard procedure for batching, and application of the product.

It is important to note, that without the 'zero defect' attitude towards the adherence of the quality assurance programme and principles during the project, the differential between results achieved during testing of the product on surface, versus product applied to the sidewall, might well have been greater. Full credit for this fine achievement must go to the site management team, for relentlessly pursuing the quality of the final applied product.

Lastly and probably the most important spin-off, is the benefit that this project has had, regarding the safety of personnel in the underground work situation. This has been unsurpassed, particularly with respect to falls of ground, which is the industries' single largest cause of catastrophic injury. To substantiate this, is the fact that not a single fall of ground has been recorded in the shaft barrel, since the application of wet steel fibre reinforced shotcrete. This SFRS product and the application thereof, should be heralded as the **'seatbelt'** of the mining industry.

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