Applications of fibre-reinforced shotcrete (Fibrecrete) support in difts at Nchanga underground mine

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Synopsis

A scraper-based block cave method has been successfully applied to extract the Lower orebody at Nchanga since the 1950s. Since inception, scraper drifts and service ways have been supported using steel arch sets fabricated to a specific design from high strength manganese steel

To reduce costs and to improve productivity, trials commenced in 2002 using fibre reinforced shotcrete as an alternative support method. One of the areas, the 2420 8E 1C trial drift, was subjected to abutment loading for several months prior to undercutting and cave mining. Shotcrete installed exhibited minor cracking shortly after application but very little deterioration thereafter. Following the success of the trial, the application of fibre-reinforced shotcrete was extended to other drifts.

This paper describes the application of fibre-reinforced shotcrete at Nchanga and outlines design and quality assurance methods employed.

Introduction

Location

Nchanga Underground Mine is one of Konkola Copper Mine (PLC) copper mines operating underground. The mine is located in the town of Chingola, 400 kilometres northwest of Lusaka.

Geological setting

Nchanga Underground Mine is located on the southern limb of the Nchanga main syncline. The syncline is asymmetric, plunging to the northwest with a 20 to 30 degrees gently dipping south limb and a steep overturned north limb. The rocks are mainly the Achean Basement Complex consisting of granites, gneisses and schists and the Late Precambrian Katanga System, a sedimentary series containing quartzites, argillites, arenites, siltstones, dolomites and limestones. The major orebodies are the lower orebody (LOB) hosted in argillaceous shale locally known as the lower banded shale (LBS) and the upper orebody (UOB) in a feldspathic quartzite (TFQ). The Nchanga Underground Mine extracts the LOB. Towards the east of the main syncline the rocks are closer to surface and mining is carried out from the Nchanga Open Pit where mainly the UOB is mined.

Mining method

The lower orebody from the Nchanga underground mine is extracted by continuous advancing longwall block caving mining method. The method involves undercutting a competent arkose that is broken by blasting subsequent to which an incompetent overlying transtional arkose/ shale layer and the lower banded shale cave due to tensile forces developed in the undercut crown after the blasted arkose rock has been drawn.

The development layout consists of a trough drive on the undercut level located 1.8 m below the assay footwall (AFW) and scraper drifts 6 m below the trough drive on the extraction level. Both the trough drive and scraper drifts are oriented parallel to strike. Caved ore drops from the undercut level to the scraper drifts via a series of finger raises developed from the scraper drifts to the trough drive. The ore is then scraped along the scraper drifts into a sub transfer chute to a transfer drift located about 20 m below the AFW, well in competent footwall rocks and from there to the main tramming level. Access to the scraper drifts is through a Service Drift developed along the dip of the orebody.

A typical block is 120 m long along strike and 80 to 100 m along dip and is serviced by a single service drift located in the centre of the block. One service drift caters for several blocks along dip and is extended as mining progresses down dip.

Undercutting and hence caving in a single block is started from two positions along a single trough drive and progresses down dip at the rate of 4 pairs of drives per year. Multiple blocks along strike can be caved at the same time. Ore tonnage in a single scraper drift currently ranges from 15 000 to 30 000 tonnes and once the ore has caved, production from a single scraper drift can last up to 4 years. In the past tonnages ranged from 30 000 to 60 000 tons and production would last up to 6 years.

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Geotechnical characteristics

Rock mass condition

The rockmass condition in the main LOB production area varies along the stratigraphic column from very good in the footwall rocks comprising arkose and granite through to a very weak and incompetent transitional Arkose unit, which forms the base of the lower orebody and a poor to moderately poor orebody shale. Generally, the rock mass condition in the footwall where the extraction and service excavations are located gets poorer towards the fringe areas where the orebody is thin.

Stress environment

The *in situ* stress levels in the current mining areas are generally low due to the relatively shallow depth of the operations. No stress measurements have been carried-out but it can reasonably be assumed that the stress tensor is generally similar in terms of orientation relative to the bedding plane as the stress tensor measured at Konkola Mine and Mufulira Mine. The major principal stress is generally sub-vertical (45–60 deg) and normal to sub-normal to the bedding plane (60–90 deg). The intermediate and minor principal stresses are almost equal and oriented parallel to sub-parallel to the bedding plane. The K-ratio is 0.85.

The initiation of caving from multiple positions along a drift and opening up several blocks along strike does lead to creation of small abutments in which high induced stresses occur. Other zones of relatively high induced stresses are the down-dip side of the caving block. In some cases, production requirements caused opening up of several faces along dip as well, thus creating more zones of high stress at the caving block boundaries.

Excavation damage

Excavation damage is mainly caused by high mining-induced stresses that are generated in small remnant pillars, closure positions and areas in the caving front abutment as discussed in the preceding section. Damage occurs mainly in the scraper and service drifts. Due to the caving sequence, a scraper drift or part of the service drift are subjected to cycles of very high loading when caving of drifts up dip takes place and suddenly become de-stressed when the cave front advances down dip. Further loading and unloading cycles are generated as the finger raises are pulled or put off draw during extraction of the caved rock.

Common types of damage are sidewall spalling, damage of pillars left between finger rises, widening of the brow of the finger raises and slabbing in the roof as a result of high horizontal stresses generated in the middling between the trough drive and scraper drift if this middling is too small. Mild rockburst conditions have been experienced in some cases.

Ground control strategy

For a very long time since the early ’50s when mining commenced ground control consisted of support installation in damaged excavations. Some roof bolting was carried out as primary support after development but this got damaged as the ground condition deteriorated.There was no rock engineering input in caving sequences and rates to minimize or reduce conditions that would lead to adverse stress conditions.

Support system

Since inception, scraper drifts and service ways have been supported mainly using steel arch sets fabricated to a specific design from high strength manganese steel. Roof bolts were installed in less severe ground condition areas. The sets were installed when damage to the excavation had already occurred or in some rare cases before damage had occurred where experience showed that damage would occur.

Steel sets construction and performance

A steel set as installed at Nchanga is an arrangement of fabricated pieces of steel held together by fish plates to form an arch. The arches are linked together by spacers and U bolts. The steel set arrangement is lagged with timbers to form a canopy. The space between the arch set arrangement and the boundary of the excavation is supposed to be filled with timbers to get complete contact between the set and the rock mass.

The support system, if properly installed, provides passive support both in the sidewalls and roof of the scraper drifts. Failure of the support, however, does occur sometimes. The failure occurs in the form of:

- cracking of parts of the sets due to impact of falling rocks where the timber lagging had not been done properly
- buckling due to excessive point loading as a result of improper filling of the space between the set canopy and the periphery of the excavation to distribute the load evenly
- total collapse of the system due to loading as a result of excessive deformation of the rockmass.

When damage occurs, production is disrupted due to loss of access. Expensive and time-consuming rehabilitation work has also got to be carried out.

Fibrecrete trials

Failure of the conventional support system to provide satisfactory support results to control ground failure and the frequent requirement to carry out rehabilitation work prompted the mine to look for alternative support systems. The motivation was also enhanced by the need to cut support costs per ton of ore produced. In the past when a single scraper drift would generate between 30 000 and 60 000 tons, the cost would be $1.9 to $3.8 per tonne. Currently, the tonnages in the scraper drifts towards the fringe areas where the orebody is thinner are between 15 000 to 30 000 tons giving an average support cost per tonne of $3.8 to $7.6.

Recent support trials and observations in mines in South Africa indicated that fibrecrete could provide an effective support system in stressed and mild rockburst conditions prevailing at Nchanga Mine.

Trial area

The first trial area was in 2420-8EB block where severe rock failure and mild rockburst conditions were experienced in 2001 due to high stress conditions in the area. The rockbolts and steel sets that were installed failed. Steel sets were being replaced at an average rate of four or more times in a year in one place. The trial was carried out on one drift, the 2420 8E 13B drift. This drift had been subjected to abutment loading for several months prior to undercutting and cave mining.

Design considerations

The complex interaction between the failing rock mass around an underground opening, and a layer of shotcrete of varying thickness with properties that change as it hardens, defies most attempts at theoretical analysis. With the development of powerful numerical tools in recent years it will be possible to explore the possible support-interaction behaviour of shotcrete.

Due to limited numerical analysis capabilities the design of fibrecrete requirements at Nchanga Mine relies very heavily upon rules of thumb and precedent experience from various sources in literature. Empirical design considerations that give suggested shotcrete requirements for various rock mass types and anticipated failure modes (Hoek, 2001), Annexure 1, was used in the initial selection of required shotcrete thickness by comparing observed conditions on the mine and those encountered elsewhere. The fibrecrete strength requirements were based on reference to trials in South African mines where conditions were thought to be similar to conditions being experienced locally.

Mix requirements

The Nchanga fibrecrete dry mix is pre-packed in 30 kg bags and contains the following materials in quantity.

Installation of fibrecrete

The fibrecrete support is installed by two contractors working in different areas. The contractors supply the fibrecrete material according to the specifications provided above. The contractors use a RocMax 90 dry mix machines. The application rates are between 10 to 15 m^2 per shift or 2 to 3 linear metres, compared to 1.5 linear metres advance per week.

To ensure good quality work on fibrecrete installation, the contractors are required to have well-trained operators who produce excellent quality shotcrete manually. The work areas are normally well lit and ventilated.

It is a standard practice that the areas scheduled for fibrecreting are rockbolted prior to fibrecrete application.

Quality control

The quality of the final fibrecrete product is closely related to the mix used as well as application procedures used. These procedures include: surface preparation, nozzling technique, lighting, ventilation, communications, and crew training.

The contractors are guided on the dry-mix design. Rock mechanics personnel randomly check the pre-mix bags to ensure compliance with stipulated standards.

To ensure that the stipulated thickness is applied, the contractor is expected to put 100 mm long nails in a ring at 5.0 m intervals and to drill two core samples every ten linear metres, one in the roof and one on the sidewalls alternately.

The core samples are later tested by KCM rock mechanics personnel to obtain the uniaxial compressive strength. In addition, the contractors do compressive strength tests on cubes at their own expense. The results are made available to the project engineer to verify the applied fibrecrete conforms to the design mix. EFNARC panel tests are not being carried out but a good correlation on the performance and the compressive strength has been obtained from observation. A 24 MPa strength is normally adequate after 3 weeks. Plans are underway to establish a shotcrete testing and quality control facility to cater for all KCM mines at the Nchanga Open Pit soils laboratory.

Table I

Fibrecrete dry-mix design

	30		25	15
	Mass (kg)	Per cent	Mass (kg)	Mass (kg)
Cement (50 kg bag) 17–22%	6.00	20.00	5.00	3.00
Sand (grade No. 2) /tonne (74–78%)	22.80	76.00	19.00	11.40
Condensed silica fumes (CSF) 1.8%	0.54	1.80	0.45	0.27
Fibres (polyprene) per kg 2.2%	0.66	2.20	0.55	0.33
	30.00	100.00	25.00	15.00

Table II

Fibre-reinforced shotcrete performance

Area/drift	Condition	Any change from previous	Comments	Percentage drawn to date	Date installed
2420-8EB/C Service Drift (13B-7C)	Good	Hairline cracks less than 1 mm	Cracks have not changed since 2002 when first observed	N/A	28.10.02
2420-8EB 13B	Good	Hairline cracks less than 5 mm	Cracks have not changed since 2002 when first observed	97	28.10.02
2420-8EC 1C	Good	Hairline cracks less than 1 mm	Cracks have not changed since 2003 when first observed	79	12.03.03
2420-8EC 3C	Good	Hairline cracks less than 1 mm	Cracks have not changed since 2003when first observed	78	05.03.03
2420-8EC 5C	Good	Hairline cracks less than 1 mm	Cracks have not changed since 2003when first observed	64	07.03.03
1130-18WC Service Drift (4C-14C)	Good	Hairline cracks less than 1 mm at 7C position	Cracks have not changed since 2003when first observed	N/A	23.10.03

Performance of fibrecrete at Nchanga Mine

In the four years since fibrecrete support was first installed, it has performed beyond expectation. Table II indicates the observations made in areas where fibrecrete had been installed.

Two of the fibrecrete supported blocks, 1130-18WC and 2420-8EB, are adjacent to areas where steel sets had been installed. Areas with steel arch set support experienced severe deterioration in ground conditions requiring frequent rehabilitation work in a year in the same place. In fibrecreted areas no deterioration in ground condition has been observed so far other than hairline cracks that have not changed for the past three years, as shown in Table II.

Based on these observations and engineering judgement, it was concluded that fibrecrete support is a suitable support system and could be tried for a variety of situations on the mine. The use of fibrecrete has therefore been extended to several areas, which include a total of 1000 m in 10 service drifts and 1650 m in 110 scraper drifts over a 15 m stretch in each drift, a tip area, 100 m of a service incline and 20 a metres stretch of tramming haulage.

Further, because of the better than expected results obtained, trials with thickness reduced to 75 mm from 100 mm are being considered. The trials in other areas will combine steel sets and fibrecree. It is hoped that these trials will contribute towards understanding the complex nature of how fibrecrete interacts with other support components to provide a cost-effective support system.

Conclusion

Fibrecrete support used in combination with rockbolting has proved to be a cost-effective support system and has been incorporated as one of the support systems on the mine

Further trials are being carried out and it is expected that fibrecrete will replace steel set support in the near future.

Shotcrete support has several advantages over other support systems. Production personnel underground especially scraper drivers, enjoy working in a relatively safe environment where barring down has been minimized. Support costs have also been reduced significantly. Fibrecrete support unit cost is $500 per metre advance, while steel set support costs $1900 per metre advance.

Fibrecrete application requires constant attention to the supply pressure and volume of the mix, water and air to ensure that the fibrecrete is conveyed to the nozzle in a continuous, uninterrupted flow. The skill of the nozzle-man is important as the quality of the finished job depends on maximizing compaction while at the same time minimizing rebound and overspray.

References

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ANNEXURE 1:

Shotcrete technology—empirical design considerations. (Adapted from E. Hoek, Practical Rock Engineering 5-Excavation and Shotcrete support: May 2001)

Part of summary of recommended shotcrete applications in underground mining, for different rock mass conditions			
Rock mass description	**Rock mass behaviour**	**Support requirements**	**Shotcrete application**
Jointed metamorphic or igneous rock. High stress conditions.	Combined structural and stress controlled failures around opening boundary	Retention of broken rock and control of rock mass dilation	Apply 75 mm plain shotcrete over weldmesh anchored behind bolt faceplates or apply 75 mm of steel fibre reinforced shotcrete on rock; install rockbolts with faceplates and then apply second 25 mm shotcrete layer. Thicker shotcrete layers may be required at high stress concentrations.
Bedded and jointed weak sedimentary rock. High stress conditions.	Slabbing, spalling and possibly squeezing	Control of rock mass failure and squeezing	Apply 75 mm of steel fibre reinforced shotcrete to clean rock surfaces as soon as possible; install rockbolts, with faceplates, through shotcrete; apply second 75 mm shotcrete layer.
Highly jointed meta-morphic or igneous rock. Low stress conditions	Ravelling of small wedges and blocks defined by intersecting joints	Prevention of progressive ravelling	Apply 50 mm of steel fibre-reinforced shotcrete on clean rock surface in roof of excavation. Rockbolts or dowels may be needed for additional support for large blocks.
Highly jointed and bedded sedimentary rock. Low stress conditions.	Bed separation in wide span excavations and ravelling of bedding traces in inclined faces	Control of bed separation and ravelling	Rockbolts or dowels required to control bed separation. Apply 75 mm of fibre reinforced shotcrete to bedding plane traces before bolting.
Heavily jointed igneous or metamorphic rock, conglomerates or cemented rockfill. High stress conditions.	Squeezing and 'plastic' flow of rock mass around opening	Control of rock mass failure and dilation	Apply 100 mm of steel fibre-reinforced shotcrete as soon as possible and install rockbolts, with faceplates, through shotcrete. Apply additional 50 mm of shotcrete if required. Extend support down sidewalls if necessary.
Mild rockburst conditions in massive rock subjected to high stress conditions	Spalling, slabbing and mild rockbursts	Retention of broken rock and control of failure propagation	Apply 50 to 100 mm of shotcrete over mesh or cable lacing, which is firmly attached to the rock surface by means of yielding rockbolts or cablebolts