High performance ore-pass lining

In recent years, investigations have been carried out in successive stages into the development and application of a high performance concrete (HPC) mix, designed to withstand the rigorous environment of ore/waste passes. These have now reached a point where previous industry standards, for such concrete performance, have been exceeded several times.

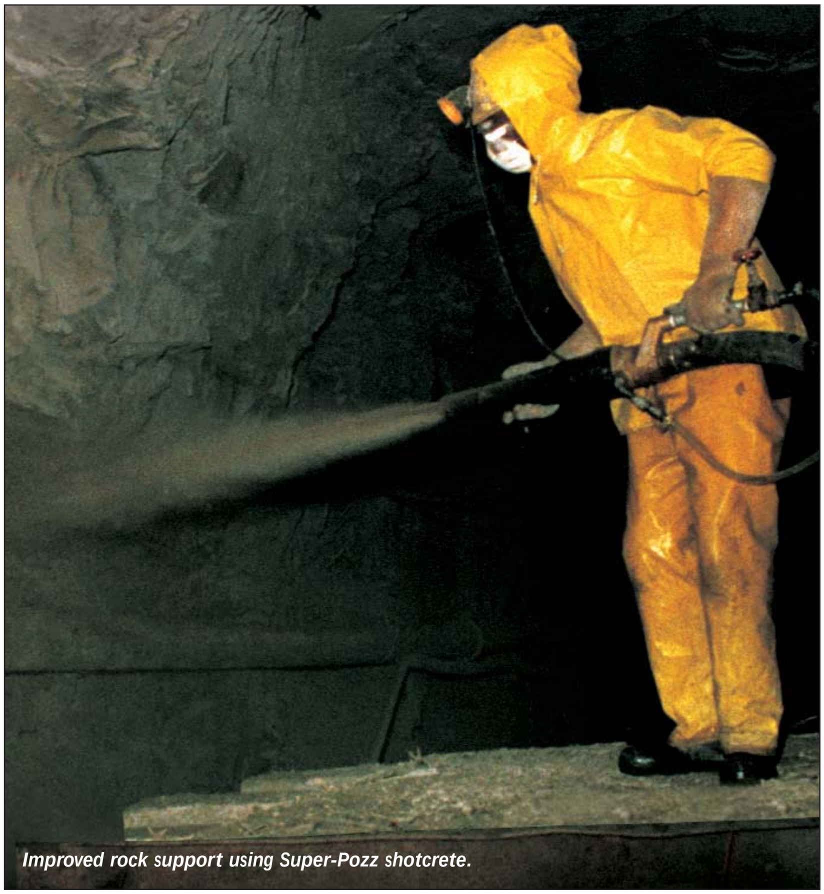
Andrew Parrish, Semane GP, South Africa, reviews this development and other usages of HPC within the South African mining industry.

Ore-passes (or rock passes) are key elements in underground mining operations and much effort is spent in keeping them operational. They are subject to complex environmental conditions including impact, abrasion, blasting shock, stress changes, geological influences and attack by aggressive agents such as mine water and ground water.

Such conditions negatively affect durability and longevity, and hence working life. Much effort is applied to ensure basic durability during the design stage by using optimum sizes, length, orientation and rock support (where necessary); but a key element is the interface between country rock and transported material, i.e. the actual wearing surface provided by the lining. This has been traditionally formed from cast in-situ concrete; the intention being to provide a strong, durable wearing surface with known characteristics.

An initial review of the prevailing rock pass lining methods within the industry confirmed that the lifespan of the linings was generally substantially less than anticipated. This was despite efforts to increase durability by increasing the compressive strength of the concrete lining material, typically up to 100 Mpa (N/mm^2).

An alternative approach was therefore required. The concept of increasing compressive strength in isolation was fallacious, and a paradigm shift, in both materials and methods, was necessary to architect and optimise a lining system. The approach taken was to examine all the factors involved in reducing durability and to build-in the necessary counter-measures in the process. This implied that utmost care would be taken in the choice of materials, the supply to site, batching, transportation and placing of a proven material.



Improved rock support using Super-Pozz shotcrete.

The approach adopted was as follows:

- To evaluate concepts of high performance concrete with regard to impact and abrasion resistance.
- To evaluate the most appropriate materials: type and class of cement, aggregates, cement extenders, fibres and admixtures.
- To test the fresh characteristics of the mix to ensure high flow without segregation for slick line placing (vertical pipe), and pumping by mechanical means.
- To evaluate the ultimate performance of the placed and hardened concrete.

Traditionally, industry concrete linings were invariably mixed very close to the rock pass being lined. These mixes were generally harsh and required very careful handling into place to avoid problems with segregation, bleed and settlement during placing. Therefore, not only was a greater in-situ performance required, but the ideal material would also be mixed on surface, dropped approximately 2500 m vertically down a slick line, col-

First layer shaft concrete.

Shotcreting in progress.

Shotcreting in progress.

lected and pumped approximately 150 m further, and only then slick lined into the ore pass; all without segregation.

With the objective of improving the ore-pass lining concrete, Semane GP, a specialised materials consultancy, believed that this was best achieved not by the use of new methods but by the intensive optimisation of existing materials and methodology. After extensive research and testing, it was found that significant benefits accrued from carefully selected materials and judicious mix designs. It was found that the ultimate performance was increased dramatically with the use of the following material types.

Cement

It is widely accepted that calcium aluminate cement based concrete will outperform other equivalent cementitious base concretes in terms of abrasion resistance. However, the use of Portland cement based mixes provided a viable alternative in terms of material cost and performance. The use of CEM I 52,5 was found to be the most appropriate.

High performance cement extenders

Research and experience showed that the use of super-classified fly ash coupled with silica fume had a great potential for achieving very high strengths, particularly over longer periods. The total addition of these pozzolans was 15% of the total binder content with the ratio of super-classified fly ash/silica fume at 1:1. Additionally, the super classified fly ash reduced the water demand and preserved the integrity of the paste matrix both with regard to prevention of cracking and the resistance to aggressive attack.

Super-classified fly ash is the very finest fraction of PFA (average particle size of 4 - 5 µm), removed from the bulk powder by additional classification. This ultra-fine fly ash (Super-Pozz®) is commercially available in South Africa from Sphere-Fill Ltd. The addition of Super-Pozz®, typically at a rate of 8 - 15% by dry weight of cement, is a beneficial constituent in high performance and sprayed concrete applications.

Silica fume has been used worldwide for many years and its benefits in both high performance and sprayed concrete applications are well documented. Though the addition of silica fume is acknowledged in improving durability, its addition in concrete generally corresponds to an increase in water content and/or admixture dosage required in improving the workability and handling properties of the fresh concrete. Blends of super-classified fly ash and silica fume are complementary, in that super-classified fly ash provides the water reduction and workability to the mix, and silica fume promotes accelerated hydration; both products synergising to improve the overall strength profile of the mix.

Admixtures

The use of highly developed admixtures was necessary to create flow, minimise segregation and to increase workability retention. The new generation polycarboxylate ether (comb polymer) superplasticisers, such as Glenium®, and Optima®, manufactured by MBT and Chryso respectively, are very effective in providing low water:binder ratio mixes, whilst improving the workability retention of the concrete.

Aggregates

The most important aspect of abrasion resistance is the bond between the aggregate and paste; if this bond is unsatisfactory the aggregate particles are easily plucked from the matrix and the concrete then suffers rapid degradation. Aggregates for ore-pass lining concrete must be hard, durable, of good shape, consistent in grading and free from micro cracking. The maximum particle size for ore-pass lining is strongly suggested at between 10 - 13 mm. The use of andesite aggregates has been found to be extremely beneficial for this type of application.

Fibres

Fibres are an essential and necessary component to the system in that they provide the following benefits:

- Drying shrinkage control to preserve the integrity of the paste matrix and to prevent weakening of aggregate/paste interface.
- Segregation prevention.
- Impact and blast resistance.
- Ductility.
- Prevention of spalling.

It was found that a combination of both micro and macro-filament synthetic fibres performed better than steel fibres in this type of application.

HPC for underground roads

Following the successful research and development of the ore-pass lining mix, Semane GP adapted the principles of HPC to provide a concrete mix for the underground roads. Two very large underground operations required the use of concrete for high speed tramming; and sections of these roads, which had been heavily trafficked, were showing signs of distress. The distress was not with regard to uncontrolled cracking but rather to the reduction in profile due to abrasion. The type of distress indicated that the impact and subsequent failure was related not to the structural capacity of the road prism but rather to the lack of resistance to abrasion and point loading impact caused by the grinding action of the LHD (front-end loader) wheels and buckets. The concrete used was typically 60 MPa but not designed as HPC. An alternative approach was proposed, as described below:

Design requirements

- Adequate resistance to abrasion and impact (HPC).
- High compressive strengths (>80 MPa).
- Batched on surface and supplied underground via slick line, collected in a re-mixer (agitator).
- High initial flow, suitable for the type of placement method to be adopted.
- Flow retention over time.

As the roadway concrete mix would not suffer the extremes of the ore-pass environment, it was acceptable to adjust the high performance concrete principles to suit the main effects of impact and abrasion, whilst compromising on the strength and ductility of the mix.

A research and testing programme was initiated to evaluate appropriate mixes, incorporating the following:

- High, but appropriate compressive strength.
- CEM II/A-M (L) 42,5 N.
- Silica fume.
- Super-classified fly ash.
- Optimum dosage of total admixture.
- Optimum dosage of synthetic fibre.
- High curing temperatures (appropriate to deep level mining).

The mixes were similar to the ore-pass designs but certain modifications were made. It was found that:

- The use of super-classified fly ash only (rather than the use of super-classified fly ash and silica fume) was of benefit. The super-classified fly ash, with its ideal fineness and spherical shape, decreased the water demand and imparted high compressive strength gains at early and late ages.
- The use of smaller fibres was of benefit rather than the larger diameter polyfibre, particularly for slick line operations.
- The use of a new generation superplasticiser from Chryso was found to be a key component, aiding flow and improving the workability retention (minimum 4 hrs) at elevated temperatures.

HPC as steel fibre reinforced shotcrete

The application of steel fibre reinforced shotcrete (SFRS) is a well-known concept and method of support (both primary and final lining) within the tunnelling industry. With the growing use of sprayed concrete as a permanent construction material, demands on its durability characteristics have increased proportionately. Different climates, rock movement and aggressive water can reduce the quality and durability of the applied sprayed concrete within a relatively short period. In addition, low humidity and high ventilation conditions, in underground projects, often leads to shrinkage cracking. Cracks not only represent a mechanical damage that reduces the static performance of a structure, they also open the door to chemical attack.

The most promising approach for increased durability of sprayed concrete is obtained by a combination of counter-measures: low water:binder ratios, type of cement, additive/fibres, proper curing and good working practice. A typical example of such an approach is outlined below.

Surface batching plant.

Underground.

Shaft lining

SFRS was specified for use in a very deep shaft located in dynamic rock conditions. The design parameters assessed included early age and long-term compressive strength, in-situ strength, energy absorption capabilities and yield. Additionally, the placed sprayed concrete (shotcrete) was required to be sufficiently impermeable to ensure long-term durability of the fibre/concrete matrix. The design compressive strength target was a minimum of 60 MPa. Using the EFNARC (European Federation for Sprayed Concrete) 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 requirement of at least 5 MPa after 48 hrs and the ability to absorb 400 Joules of energy after 4 - 8 hrs. The EFNARC specifications for sprayed concrete were used for all shotcrete tests conducted. Based on the results obtained, the addition of a 40 mm long austenitic stainless steel fibre was chosen as the shotcrete reinforcing ingredient that would provide the required ductility and long-term durability, when combined with the chosen admixtures, aggregates, cement and water.

Following the trial mix process, the mix finally adopted was a complex blend of very high quality materials, with each constituent being included for a very specific reason.

The constituents were as follows:

- *CEM I 52,5 cement*: a very basic constituent but of great importance to create high early and final strength in a cost effective manner for this application.
- *Super-classified fly ash*: added to reduce water demand, assist pumpability, increase resistance to chemical attack and provide long-term strength gain. By incorporating the super-classified fly ash, the cohesion and adhesion properties were also proportionately enhanced.
- *Aggregates:* those used were of a specific quality and consistent grading within narrow limits.
- *Hydration control admixture*: to create long open time, to assist in fibre dispersion during mixing, and to facilitate flexibility in placing.
- *An internal curing agent and concrete improver*: a very necessary product especially with crushed aggregates and lack of external curing, available from MBT.
- *Stainless steel fibres*: austenitic, very high tensile strength and with high corrosion resistance.
- *Microfilament polypropylene fibres:* although used at small dosages they were extremely important element of the mix.
- *Sprayed applied concrete accelerator*: a key component to create high early strength and continued long term stability.

The SFRS was very successfully applied for this project; a total of 7500 m^3 being placed within the shaft barrels.

Conclusion

The projects briefly described above illustrate the great potential for a high quality material such as super-classified fly ash, in creating appropriate performance and durability in the aggressive and demanding environment of underground mining construction. It is anticipated that the future developments of high performance mixes, for applications other than those outlined here, will proceed hand in hand with the use of new developments in cement extenders and admixture technology. For example the use of self-compacting concrete (SCC) will increase in the mining industry, and the addition of super-classified fly ash with polycarboxylate ether admixtures, in this type of concrete, is known to be of great benefit, particularly in South Africa where aggregates are not well suited to this application.

Enquiry no: