New Developments in Large Areal Coverage Supports in South Africa

L. Wojno and J. Kuijpers

CSIR Mining Technology Division
P.O. Box 91230, Auckland Park 2006, Republic of South Africa

Abstract: A strong need exists for large areal coverage support for mine excavations in fragmented and discontinuous rock, both in tunnels and tabular stopes. In addition, problems exist with maintaining stability of pillars exposed to high stresses, stress changes and/or weathering. Two new potential solutions to address these support requirements are discussed in this paper together with preliminary data on the proposed support performance. The support solutions are: a sprayable, thin, strong and flexible membrane support, and an inflatable, re-usable and resilient stope/gully support. The user-friendly membrane support could present an alternative to conventional shotcrete in many applications, while the inflatable support could replace individual support units and even small pillars in the support of tabular stopes and gullies.

Key Words: mine support, areal coverage, rock mechanics, support design, pillar

Introduction

For some years it has become increasingly apparent that one of the essential requirements to improve the safety and stability around highly fractured deep level tunnels and stopes is an increase in the areal coverage provided by the support. Problems with maintaining stability of excavations by preventing falls of grounds and/or unavelling of low cohesion rock are not confined to high stress environments but they are also experienced in shallow mines, particularly those located in a disturbed rock mass. Such conditions are frequently observed in South African platinum mines and in some collieries.

Rock related accidents in the South African gold mining industry account for more than 55% of the total fatalities and about 30% of the total injuries (Glisson, 1997). The majority of these occur in the face area of the tabular, low mining height stopes and gullies typical of the gold mines.

It appears that under poor hangingwall conditions, current temporary tunnel, face and gully support methods are not able to adequately prevent accidents either due to rockbursts or rockfalls. Falls of ground do occur between individual support units and can cause injuries to miners and dilution of the ore. To address these problems, the concept of a thin, flexible, spray-on coating has been developed. Such a support “fabric” would cover most of the surface area of the hangingwall and could prevent or significantly reduce fall out of the relatively small individual blocks which in turn would go a long way in improving safety and stability of excavations.
Another group of problems is related to the overall stability of stope gullies being adversely affected by poor performance of timber packs which are the most common gully support. Unsatisfactory support characteristics of timber packs, labour intensity, fire hazard and high cost created a strong need for a better, user-friendly and cost effective gully support which would also allow for more efficient ventilation/cooling of stope working areas. In response to such a need, the CSIR Mining Technology Division in collaboration with the industry developed a concept of an inflatable, resilient and re-usable stope/gully support which could ameliorate problems experienced with the timber pack support.

Spray-on Flexible Structural Membrane Support (EVERMINE)

In the process of developing a strong, thin, well bonding and sprayable membrane support, a number of coating materials were eliminated as too expensive, environmentally hazardous, or simply too difficult to apply in the extremely demanding mining environment where the ambient temperature can be in excess of 32 °C, the relative humidity can reach 100 %, rock face temperature can exceed 40 °C and the air velocity is very low.

Intensive investigations carried out by the CSIR Mining Technology Division in collaboration with Stratabond S.A. (Pty) Ltd have resulted in the development of the EVERMINE product which is an acrylic based, fibre reinforced coating material that appears to have the potential for providing temporary support for mine excavations in poor rock conditions. A further possible application of the material is in the stabilisation of failing pillars by coating their perimeter with this strong, well bonded and flexible structural membrane, which has the potential to prevent pillar scaling and subsequent unravelling of the broken rock resulting in improved overall pillar stability. Not only would the coating reduce the likelihood of the pillars failing by increasing the strength, but it would also seal the pillars against direct ingress of deleterious fluids, which could contribute to time dependent failure.

The EVERMINE is sprayable and adheres strongly to the rock surface producing a uniform coating even if sprayed on irregular surfaces.

The basic properties of this structural membrane coating material have been quantified as follows:
* Tensile Strength ranging from 3 MPa to 4 MPa depending on the fibre content.
* Elongation: >45 %
* Water based, easily washable before curing
* Non-flammable and non-toxic
* Optimal thickness of the structural membrane support: 3 mm.
* Flexible (25 mm diameter tests) and impact resistant (7.4 J).

At present, preliminary laboratory and field investigations are being carried out to evaluate the potential use of the coating, with the main objective to quantify the support effect of such a structural membrane on the stability of tunnels, stopes and pillars.
Stabilisation of pillars

While the primary function of the membrane is to maintain the integrity of fractured and fragmented hanging and sidewalls, a potential secondary effect is associated with the (residual) strength of the fractured and fragmented excavation walls. This is especially of importance in the case of abutments, as it determines to a large extent the post failure behaviour of such abutments.

For all practical purposes it can be assumed that rock loses strength after failure, irrespective of the underlying mechanisms which control such failure. In the post failure stage the hard rock material will possess a residual strength which is less than its peak strength. This residual strength is the most critical parameter controlling the load bearing capacity of over-stressed abutments such as sidewalls of deep level excavations and pillars. K. Barron (1982) investigated the theoretical strength of pillars by means of limit equilibrium analyses and derived an equation for the vertical stress distribution in the failed zone of a pillar abutment. This equation is an exponential function in which the residual strength is linearly related to the vertical stress.

Related numerical analyses also showed that the residual strength controls the post yield behaviour to a large extent. (Wojno and Kuijpers, 1997). As it is in practice possible that unsupported and unconfined rock cannot maintain any residual strength, some form of support is required to provide the failed material with a (minimum) residual strength. The function of the membrane in the case of pillar and abutment stabilisation is therefore the provision of such a residual strength. The effect of the residual strength is exponentially amplified with increasing distance into the abutments, due to the frictional resistance of the fractured rock.

In order to investigate this mechanism, laboratory tests have also been performed. An example of the confining effect of the EVERMINE coating is illustrated in Figure 1 where the load deformation response of an uncoated and a coated quartzite specimen is shown. Both pillar specimens were cut from a 150 mm diameter core (UCS of 294 MPa) and had a height of 30 mm (width to height ratio 5:1). The uncoated specimen failed violently and completely disintegrated while the coated specimen effectively showed a hardening response after failure. This specimen was in fact so well confined that the hardly damaged core of the pillar indented the steel loading platen by approximately 8 mm.
The difference in results indicates that the violent behaviour, which is so typical of this rock type under normal circumstances, can be suppressed and even eliminated by the application of a small amount of flexible support such as this coating. The practical implication of these results is that it might in principle be possible to curtail the energy which is released during a local rockburst by the application of such a support in rockburst prone areas. In deep level South African gold mines such conditions are not uncommon and the use of a structural coating could very well be justified there.

Although these tests provided an indication of the potential reinforcing effect of the coating, it was not clear to what extent the boundary conditions affected the results. For this reason it was decided to use mortar specimens, cast in moulds, which were designed in such a way that square specimens with an I-shaped cross sectional area were formed. The top and bottom flanges, representing the "hangingwall" and footwall" respectively, were both clamped by a solid steel frame and vertical loading was applied onto the surface of these flanges. The Uniaxial Compressive Strength of the mortar was approximately 100 MPa and behaved in a brittle manner under those conditions. These tests were considered to represent a pillar cut in a homogeneous medium, thus eliminating a pillar/steel loading platen interface.

Coating of the 2:1 specimens resulted in a minor improvement in the post failure behaviour compared to the uncoated specimens. Typical results are shown in Figure 3 where it can be seen that a reduction in strength occurs after approximately 15-20% of vertical deformation. This deformation coincided with the cracking of the coating, which apparently reached the limit of its stretching capacity at that point. It is not clear if the peak pillar strength could have been maintained if the coating would have been able to stretch further. However, these results indicate quite a different failure mechanism than the one which occurred in the quartzite specimens. While brittle failure dominated the behaviour of the quartzite specimens up to a width to height ratio of 5:1, the mortar specimens showed evidence of both brittle and plastic failure.
even down to a width to height ratio of 2:1. The core of the specimens remained undamaged and appeared to deform plastically. As the primary function of the structural membrane is the maintenance of the integrity of a fractured/fragmented medium, it might not produce any significant effect if applied to a material which is not fractured or fragmented.

Figure 3. Coated Mortar Pillar models - W:H ratio 2:1

Although it is not clear to what extent the material properties or the boundary conditions contributed to the observed behaviour, it is obvious that the coating had a limited effect on the post failure behaviour of the mortar specimens due to the fact that brittle failure only took place in the skin of these specimens. The rest of the specimens remained coherent and was evidently subjected to plastic deformation without a loss of internal integrity.

Stabilisation of fractured/fragmented hangingwalls

In order to assess the effect of the structural coating on a stability of a fractured or fragmented hangingwall, some initial numerical simulations have been carried out. The discrete element program UDEC was used to represent a layered beam with a span of 20 m and a height of 4 m, which contained vertical fractures as shown in Figure 4. None of the vertical fractures completely traversed the beam while the horizontal parting planes were modelled either as continuous, planar features as in model A, or as discontinuous, interlocking elements as in model B. Model A therefore represents a situation in which a stack of individual layers can deform relatively independently of each other, while model B represents a situation which is considered to be a more realistic one for a fractured rockmass which is subjected to an unravelling process.

Both models have been subjected to gravitational forces and the support at the abutments consisted of a horizontal compressive stress of 1 MPa and a restraint against vertical deformation. In addition a vertical force of 200 kN was applied at intervals of 20 % of the span, i.e. 4 m. The EVERMINE coating was represented by a 10 mm layer which was attached to the bottom of the beam. Without that coating the beam became unstable for both models, while at the same time the stability was
reached with only a limited coating strength (0.5 MPa) in case of the interlocking layers (model B). A twentyfold increase in the strength of the coating (10 MPa) was still not sufficient to stabilise model A, in which shear deformation between individual layers could not be prevented.

**Model A**

Uncoated, non interlocking partings  Coating strength 100MPa, unstable

**Model B**

Uncoated, interlocking parting planes  Coating strength 5MPa, stable

Figure 4. Effect of coating on the stability of a fractured/fragmented hangingwall

What these models demonstrate is that the structural membrane can, by stabilising the skin of an interlocking rockmass, prevent the onset of unravelling and in such a way allow for maintaining of the stability of the rockmass itself. If such a coating is used to stabilise a non-interlocking, highly fragmented rockmass, its effect could be minimal, as the coating itself would have to carry the weight of the overlying hangingwall. It is believed however that the scenario of an interlocking rockmass is a more realistic representation of the situation around many hard rock excavations where a structural coating may offer a viable solution to the stability problem.

**Development of Inflatable Stope and Gully Support**

In South African mines with tabular ore bodies, the design of stope and gully support systems has in most cases been based on experience, past practices and cost considerations. Approximately 130 support systems have been identified in current use in the industry (Roberts, 1995). These include various support unit types with variations in spacing and support dimensions. Only a number of these systems are optimised while the rest is either being over- or under-designed.

Two important design criteria for stope support are support resistance (kN/m²) and energy absorption (kJ/m²). The former one is generally used in the industry as a guide
for the design of stope support systems in excavations where the major hazard is rockfalls (gravity) while the latter is used for stopes which are subjected to seismicity and rockbursts (dynamics).

Experience gained from various in-situ investigations around stope gully support, indicates that the most common problems with stability of gullies is related to the incompatibility of the force-deformation characteristic of the timber gully packs in response to the loading conditions generated by the deforming rockmass. Too stiff packs often cause foundation failures and too soft ones cause instability/fallouts around excavations. These problems, together with a large labour requirement for the erection of timber packs, as well as stability problems that are related to a limited yieldability of gully packs under dynamic loading, created a need for a new, gully/stope support. It was envisaged that such a support would have a performance characteristic that could be pre-designed for a specific loading environment. A recommended force-deformation curve for a deep mine gully pack was developed and is given in Figure 5.

![Figure 5. A recommended performance characteristic for a yielding gully pack (Squelch, 1995)](image)

An indication of required support resistance (static loading) and energy absorption (dynamic loading) by the gully support is provided in Table 1.

<table>
<thead>
<tr>
<th>Reef Type</th>
<th>Fallout thickness m</th>
<th>Support resistance kN/m²</th>
<th>Energy Absorption kJ/m²</th>
</tr>
</thead>
<tbody>
<tr>
<td>VCR</td>
<td>0.70</td>
<td>19</td>
<td>10</td>
</tr>
<tr>
<td>Carbon Leader</td>
<td>1.00</td>
<td>26</td>
<td>15</td>
</tr>
<tr>
<td>Vaal Reefs</td>
<td>0.55</td>
<td>15</td>
<td>8</td>
</tr>
</tbody>
</table>

The tabled fallout thickness is based on a cumulative value of 95% of all observed falls of ground in gullies, the assumed velocity of mobilised rock is 3m/s and the required arresting distance for the support is 0.1m.

A new type of support with the potential to address some of the major limitations of the conventional gully/stope support has been developed and preliminary tested. The proposed support comprises a modular, inflatable chamber that is collapsible and portable. When pressurised with water or air, it can carry significant loads of up to
hundreds of tons. The units can be reused and can be manufactured from either steel reinforced rubber or from much lighter, hi-tech reinforced textiles. Another feature that is important for mine support applications is the toughness of such a support unit which can easily be transported to a required position underground by dragging it on the rockfloor using a scraper rope.

In addition, the inflatable and flexible support can effectively transfer load and adequately engage with irregular hanging- and footwalls without a need for labour intensive wedging which is essential for the installation of timber packs.

If installed face-to-face, in addition to the support function, the inflatable units would form a ventilation barrier that could prevent excessive heat flow from the mined out areas into the ventilation system, thus reducing energy requirements for ventilation and cooling purposes. An estimate based on production data (Marx, 1997) indicates that a mine producing 2.4 million tons per annum spends on average approximately R20 million for ventilation and cooling. An estimated total cost of ventilation/air conditioning per annum in South African mines is as follows:

a) gold mining - >R870mln
b) platinum mining - >R330mln

It should also be noted that any cost efficient ultra deep mining will not be possible without more efficient air conditioning.

A prototype of the inflatable support tested in the press is shown in Figure 7.

Figure 7. A prototype of inflatable unit in the 400 ton press during a laboratory test.
Examples of the load-deformation characteristics for both air-filled and water-filled support units are shown in Figures 8 and 9, respectively.

Figure 8. Performance characteristic of the air-filled support unit.

Figure 9. Performance characteristic of the water-filled support unit.

The air-filled support offered a rather soft performance with its stiffness ranging from about 1.3 kN per mm to 2.2 kN per mm deformation of the inflatable unit, while the water-filled unit offered much higher stiffness ranging from about 32 kN per mm to 50 kN per mm deformation. Such support characteristic compare very favourably with the load-deformation curves for a number of typical gully packs with stiffnesses ranging from approximately 4 kN/mm to 16 kN/mm deformation.

Another potential feature of the inflatable support is its yielding ability which can easily be achieved by installing hydraulic valves, similar to those which proved successful in the rapid yielding hydraulic prop units. The performance of the inflatable support units can, in this way, easily exceed the requirements specified in Table 1. It should be noted however that these requirements only cater for 95% of fall outs which have been observed between existing support units. Total support requirements might therefore be different.

The large support capacity of the inflatable units could probably find application in collieries as a temporary support during pillar extractions or as even pillar replacement to improve extraction ratios.

It appears that good support characteristics of the water-filled inflatable units, together with their resilience, re-usability and yieldability under slow and rapid loading, could offer a promising and cost efficient new stope/gully support with interesting potential to ameliorate problems associated with the conventional support in gold, platinum and coal mines.

Conclusions

* Introduction of confinement to an unravelling rock wall through application of a thin, structural membrane support has the potential to improve overall stability of pillars and mine excavations
* A structural coating can prevent the unravelling of an interlocking rockmass by
stabilising the skin of such a rockmass; this may have major implications for the support strategy of excavations.

* Violent failure, in which large amounts of energy may be released, can in principle be contained by the use of a flexible structural coating.

* Failure of hard, brittle rock may be controlled by limited support resistance as this provides a minimum residual strength; this may have major implications for the stabilisation and reinforcement of excavation sidewalls and pillars.

* Water-inflatable units have the potential to offer a safe, yieldable and cost efficient stope/gully support method for deep gold mines as well as to provide re-usable support in shallow platinum and coal mines.

References


