

ROCK SUPPORT IN SOUTHERN AFRICAN HARD ROCK MINES.

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1. Abstract.

Southern Africa has a long history of underground hard rock mining dating back to the late 1800's. The rock support of underground excavations has significantly changed during this period, due to improved technology, experience gained and rock support requirements by mining and geotechnical engineers.

This paper examines the available underground rock support methods in Southern Africa with emphasis on the types and characteristics of:

- Rock bolt types.
- Rock bolt and long anchor grouts.
- Thin-sprayed liners.
- Sprayed Concrete.
- Ground consolidations through injection methods.
- Cavity and void filling with aerated cement products.



Figure 1. Wet shotcreteing used to support a new decline.

2. Introduction.

Underground mining creates excavations of varying sizes in the surrounding rock mass. This rock mass is never continuous, can be of varying rock strengths, can be traversed by geological disturbances as well as being subject to changing stress fields. Left un-supported these excavations will collapse causing injuries to persons as well as disruptions to mining.

In order to ensure the safety and life of such excavations are maximised engineers need to employ proper design and layout of these excavations as well as ensure that the correct support systems are used.

For the purpose of this paper supporting of narrow tabular excavations will be ignored and the focus will rather be on the supporting of tunnels and other large excavations.

3. Rock Bolts.

Rockbolts work by reinforcing the rock – this means they improve the strength of the rock mass into which they are installed so that the rock itself becomes part of the support system.

When rockbolts are installed they modify the ground behaviour and can prevent or restrict rock failure. They do this by transferring load from the unstable part of the rock mass to the rock bolt itself and then into the stable ground. The strength of bond between the anchor and the rock is a measure of the effectiveness of this load transfer mechanism.

For all types of bolts – mechanically anchored, friction anchored and grouted – the bond results from a combination of friction and interlocking at the bolt/rock or bolt grout and grout rock interfaces.

Steel Diameter	Yield	Ultimate Tensile Strength
14.50 mm	90 kn	110 kn
16.00 mm	110 kn	130 kn
18.00 mm	150 kn	210 kn
20.00 mm	160 kn	230 kn

Table 1. Common steel diameters used to manufacture rock bolts in Southern Africa.

3.1 Mechanically Anchored Rock Bolts.

Although the usage of mechanical bolts has declined in the Southern African Mining Market over the years these bolts are still used throughout the world today. Mechanical anchored bolts are relatively inexpensive and give immediate active support directly after installation. They can be used in a wide range of hole diameters from 25 mm to over 60 mm. Various steel diameters can be used to suite the required strengths.

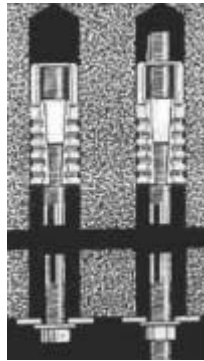


Figure 2. Typical example of a mechanical anchored bolt.

Mechanical bolts do have certain limitations in that if the correct torque is not applied on installation inadequate load will be achieved. Load is also lost through ground vibration caused blasting or other rock movement. If scaling occurs around the collar of the support hole load is also lost. If these bolt are not grouted corrosion of the steel is a problem.

To avoid the problems as mentioned above these bolts should be grouted. Grouting by means of conventional breather tubes such as used with cable bolts have had some amount of success but is time consuming and problematic as the breather tube usually winds around the bolt when tensioned, crews then stop grouting these mechanical anchors because of this. Cement capsules can also be used to grout these bolts when a slotted washer is used with a capsule loader especially designed for this application but this also has its limitations as the system is open to abuse as grouting is a secondary operation and without close supervision will not be done correctly.

Over the past few years new versions of mechanical bolts have been manufactured to enable easier more effective grouting. In Australia a bolt was manufactured using pipe (HTB), which allowed for easy effective grouting but it never achieved a great deal of success due to high cost and limited tensile strength of the pipe. More recently a mechanical bolt has been introduced into the market manufactured by using two cold rolled segments which when combined results in a hollow bar with sufficient tensile strength. Provided this bolt is used with a high quality fast setting grout, which can achieved sufficient strength when blasting close to these bolts it will allow for a good quality permanent support unit where limited yield is required.



Figure 3. Hollow mechanical anchored bolt.

3.2 Friction Bolts.

Friction bolts (split sets) are widely used in the hard rock mining industry where there is a high degree of bolting mechanisation and strata that is suitable for this medium. As the name implies, these bolts work by utilising the friction generated between the strata and the bolt. Friction anchors bolt anchors are relatively expensive and should not be used for medium/long-term support unless they are protected from corrosion, and even then their life is limited.

Friction anchors are easy to install and are popular for use in operations such as shaft sinking. They can be galvanised and cement grouted to protect against corrosion. The drill hole diameter is critical when using friction bolts.



Figure 4. Friction Bolts.

3.3 Expandable Friction Anchors

Expandable friction anchors are often used as a temporary support in metal mines and tunnels and are generally associated with highly mechanised mining. These anchors are operated by using a high water pressure system to expand the folded bolt against a pre-drilled hole. The water is then released from the system. These bolts are susceptible to corrosion and it is becoming common practice to post grout them to prevent this.

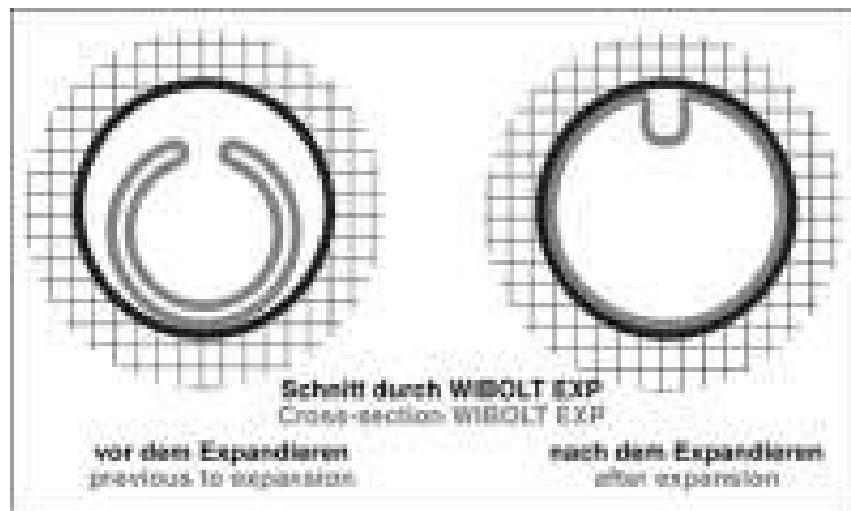


Figure 5. Expandable Friction Bolts.

3.4 Glass Fibre Reinforced Fibre Bolts.

In normal mining operations a steel rock anchor will normally be sufficient to support the rock but for certain applications such as an area where one would encounter excessive corrosion or one needs to mine through a supported area such as an undercut and normal steel rock anchors could cause problems if they end up in the ore pass system the GFR bolt would be a better option. These bolts are comparable to steel in strength can be grouted using either cement or resin grouts.



Figure 6. GFR Bolts.

3.5 Grouted Bolts.

These bolts types have been used in the mining industry for many years using both cement and resin grouts. These bolts are available in various types ranging from standard bolts manufactured from re-bar such as shepherd crooks or fully threaded bar which can be either hot or cold rolled.

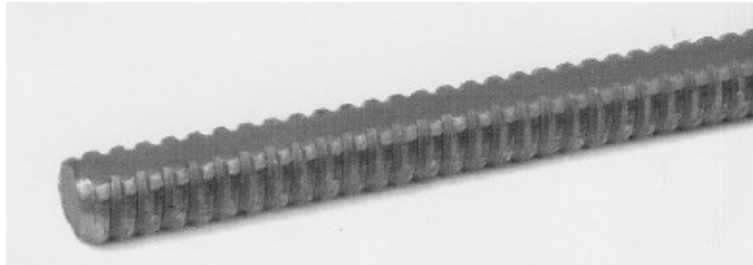


Figure 7. Fully threaded grout bar.

3.6 Cable Bolts.

There are many different types of cable bolts in use today most being longer in length than a standard bolt. These bolts types are usually used for secondary support of large excavations or in areas where bad ground conditions are encountered. Some mines install these bolts as a passive support where standard cable is grouted using a cement grout and other mines will pretension these cable bolts using a mechanical or resin anchor, these bolts can then be post grouted.

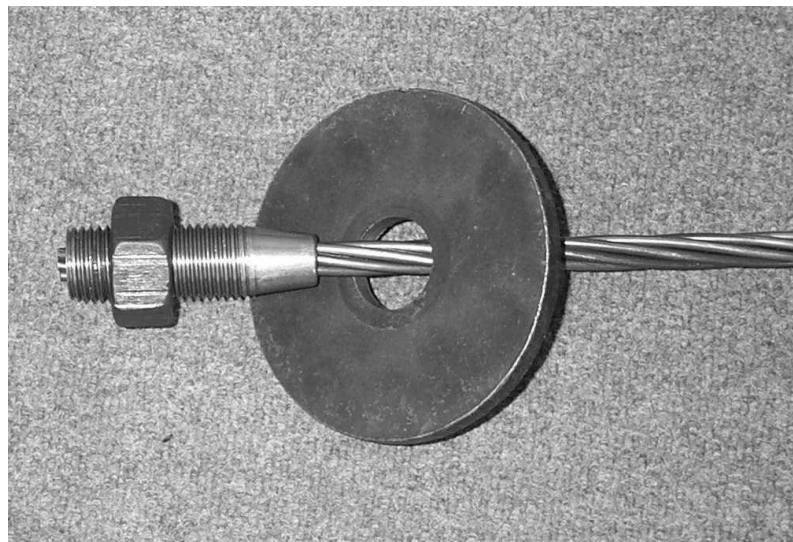


Figure 8. Flexibolt cable bolt.

4. Grouts.

Provided grouted tendons are manufactured with quality steel or cable which meets the ruling specification in the country of use the grouting of these tendons are critical to ensure that the complete installed tendon is not a weak point in the mines rock support system. Grouting will either be done with a cementitious or resin-based grout. As with any grouting medium or method there are positive and negative points and it is up to the end users and mine support designers to choose the product, which will suite their particular application.

4.1 Pumped cement grouts.

Pumped cement grouts have been used in the mining industry for many years ranging from a standard Portland Cement mixed with water to grouts formulated to meet specific requirements. These pumpable grouts have been applied using a wide range of pumps from basic relatively low cost pumps to expensive more sophisticated pumps.

There has been a trend for mines to use pumpable grouts, which have been engineered to give a high quality (figure 9) installation when compared to a basic grout manufactured using OPC with and extender and sand. Products such as Minova's Capcem® PLG and PLGF have been formulated to be thixotropic, non-shrink and suitable to pump holes up to 15.0 m in length. However close supervision is still required when using such grouts to ensure that the correct amount of mixing water is used and these grouts are mixed thoroughly.



Figure 9. Correct consistency for a pumped grout

The latest trend in pumpable grouts for standard length rock bolts is to supply the grout in a capsule form such as Minova's Capcem® Pumpable 35 Grout. These capsules are designed so that when they are soaked in water they will only absorb the correct amount of water to wet them throughout thereby ensuring the grout reaches its design strength in the required time. This grout is then applied with a easy to use cost effective pump such as the Minova Spudnik® pump (figure 10). This system allows for a cost effective easier to control quality grouting system.



Figure 10. Minova's Spudnik® Pump.

4.2 Cement Capsules.

Cement capsules (figure 11) provide a good alternative to pumped grouts. Although slower set capsules are still used in limited quantities the demand is for capsules which provide support at 1 hour such as Minova's Capcem® cement capsules, this allows people on the face to work under permanent support one hour after the support has been installed and also to blast on this support an hour after installation without damaging the installation which can occur if the grout has not yet reached strength.

Cement capsules are relatively cheap and easy to use but support crews using these capsules need to be trained in the correct use to ensure support holes are completely filled.

4.3 Resin Capsules.

Polyester resin capsules are a clean, very rapid setting (15 second to 10 minute) and easy to use grouting medium. The product is manufactured in a two component capsule form; one component contains the resin mastic and the other the catalyst or activator. When a bolt or cable is spun through this capsule it breaks the two components and mixes them. Thorough rotation of the bolt is required to ensure the resultant mix hardens.



Figure 11. Minova's Capcem® Capsules.

The relationship between the hole and bolt diameter is very important and should be between 4 and not more than 12 mm to ensure the bolt penetrates both compartments of the resin capsule. Previously this limited the use of resin to coal mines and hard rock mines with mechanised drill rigs which were capable of drilling smaller diameter holes. But the move away from integral steel in hard rock mines has allowed for the drilling of smaller holes to better suite resin installation. Equipment manufactures have also built drill rigs to operate in more confined spaces which makes resin even more suited for use in hard rock mines.



Figure 12. Lokset® resin Capsules.

Most capsule manufactures offer a range of sizes and set times that can be tailored to suite the needs of the bolting system in place and local strata conditions. This means that resin capsules offer a flexible solution to almost all bolting problems. As the size and speed of the capsule can be altered, it allows for a very flexible bolting regime which can tailored to meet

nearly all bolting situations. The ability to change the speed of set and use different set time in the same hole makes the resin cartridge ideal for use where post tensioned systems are required.

4.4 Pumped resins (PUR, epoxy, polyester).

In some places the use of pumped resins for anchoring has become commonplace. These are often used in conjunction with self-drilling anchors such as Wiborex®, and are currently used mainly for consolidating broken and friable rock in conjunction with PUR grouts such as Bevedan/Bevedol®

5. Surface Support.

Surface support includes traditional support types such as meshing and lacing and shotcretes and more recently Thin Support Liners and synthetic webbing. It is important that whatever surface support is used this needs to be combined with a good quality bolting system in order to achieve an effective support system.

5.1 Sprayed Concrete.

Sprayed concrete otherwise known as gunite or shotcrete has a long history of being used as a surface support in Southern African Mines. There are two application methods for sprayed concrete used in our mines; the dry mix and the wet mix method. More than 90 % of sprayed concrete used today is for rock support.

5.1.1 Dry-mix method.

The dry-mix method of placing sprayed concrete has been around for much longer than the wet mix method and there is a lot of know how in the mining industry, this system itself is also very flexible and is ideal for a smaller stop start operation. Shotcrete material can be pre-bagged and stored underground and used as and when required. The main drawback is the relatively high levels of dust (usually three times the allowed limit when measured) especially if the spraying equipment is poorly maintained. Rebound is also a problem when using the dry method and between 15 and 35 % of sprayed concrete is lost. This can be significantly reduced by using the new kinds of add-mixtures available from the manufacturers of these products.

Good maintenance of equipment and correct training of crews will assist in minimising the problems as mentioned above.

5.1.2 Wet-mix method.

It is estimated that about 85 % of all sprayed concrete placed for support rock today is done so by means of the wet mix-method. When wet sprayed concrete was introduced to the market it received a bad reputation due to poor equipment and little knowledge of the system, this has however changed due to know how of the system, good equipment and good concrete add-mixtures available to use with this wet-mix method of applying sprayed concrete.



Figure 13. Dry-Mix Method Spraying Equipment.

Equipment (figure 1) used to apply sprayed concrete through the wet-mix method allows for increased production 4-5 times higher than can be achieved with the dry-mix method.

The advantages of the wet-mix method compared to the dry mix method can be summarised as follows:

- Far less rebound. A loss of 5-10 % is normal with use of correct equipment and trained personnel. These figures also apply to the spraying of fibre reinforced concrete.
- Better working environment; dust problems reduced.
- Thicker layers because of effective use of admixing materials.
- Controlled water dosage (constant, defined w/c ratio).
- Improved bonding.
- Higher compressive strength and very little variation in result.
- Much larger production and consequently improved total economy.
- Use of steel fibres/ structural polymer fibres and new advanced admixtures.

5.2 Thin support liners.

Although a relatively new product in the mining industry usage of TSL's have been increasing as mining and rock mechanics engineers realise the benefit of these liners. These TSL's are usually applied onto the rock surface with a thickness of up to 4.0 mm. They are usually very flexible when compared to traditional shotcretes and their use as a structural support is not recommended.

These TSL's assist in the locking of key blocks which makes the rock mass more stable. The TSL's also penetrate cracks and joints in the rock mass, which assists in preventing movement of key blocks. TSL's also seal rock which is beneficial where rock is present which deteriorates when exposed to air and water.

TSL's can be used for the following applications in mines:

- Support between rock anchors.
- Supporting areas with limited access or logistical constraints.
- Limiting weathering.
- Reducing rock burst damage.
- Reinforcing pillars.
- Rehabilitation.
- Temporary support where aerial coverage is required to protect workers.
- Replacement of thin layers (25 mm and under) of shotcrete.

Thin support liners fall into two main categories based on chemistry:

- Non-reactive where the applied material gains strength with time typically as a result of water loss (similar to paint technology).
- Reactive where the applied material gains strength rapidly as a result of using a catalysed chemical (exothermic) system.

The choice of what system a mine will use will depend at what time the applied TSL needs to have strength. For example for the sealing of a settler a non-reactive TSL will be sufficient but using the TSL as a temporary support on the face will require a reactive TSL.



Figure 14. Supporting of a raise bore hole with a TSL

6. Other Support Methods.

6.1 Ground Consolidation.

Ground consolidation refers to the consolidation or gluing together of weak rock using resins or polyurethanes. This method of ground support is used to mine through areas where the ground is extremely fractured and weak such as a running dyke. Ground consolidation materials require specialised pumps for application and can also be used to stop water underground. Because of the bad rock conditions being dealt with, mining is generally slow and a specialised contractor is usually required to perform the work.



Figure 15. Example of loose rock consolidated.

6.2 Aerated Cements.

Aerated cements are cement grouts with large amounts of air entrained in the form of small bubbles with relative densities generally ranging between 0.3 to 1.0. Compressive strength can be as low as 0.3 MPa and as high as 10 MPa.

In the mining industry, aerated cements are used for cavity filling, ventilation walls, fire control explosion stopping's, shaft pillar removal and backfill barricades.

Aerated cements are easy to apply and training of installation crews usually can be done within a few days. Equipment to apply these aerated cements is not excessively expensive.



Figure 16. Void Filled with Aerated Cements.

6.3 Backfill.

Backfilling in mines can be for a number of reasons, which include:

- Seismic Considerations.
- Strata control improvements
- Increased percentage extraction.
- Shaft pillar considerations.
- Unusual mining conditions.
- Replacement of conventional support.
- Environmental considerations.

The types of backfill systems being used on the mines today are:

- Waste fill, where waste rock is used to fill old worked out areas.
- Plant tailings, which can be full plant tailings or classified plant tailings.
- Pastes or dewatered total tailings.
- The above systems can be used with or without binders depending on the requirements of the system.

7. Conclusion.

The subject covered in this paper is too broad to go into great detail but the intention is to show what type of support is available and being used in the supporting of underground mines today. Each of the methods and materials covered into this paper has an application in the mining industry and enough detailed information and track record is available on all of these products and to ensure today's mining and rock mechanics engineer uses the correct product for the correct application.

8. Acknowledgements.

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