Resin bolting in South Africa platinum mines with a focus on development and stoping operations

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The South African mining industry is at present in transformation regarding safety of their mining operations. Never has there been more of a drive by all concerned to make our operations safer and improve our accident rates to be comparable to the first world countries. The industry is striving to meet the 2013 safety milestones set by the Department of Mineral and Energy Affairs. The authors wish to explore the current and potential application of such resin bolting in mechanized and conventional stoping and development operations. We further want to investigate the practicality of making use of these new generation support product to make support operations safer as well as enhance productivity of operations in the stopes and development excavations.

This paper will address resin bolting technology and will deal with the following aspects:

- Introduction and history to resin bolting technology
- Bolting theory with a focus on resin capsules
- Advantages and disadvantages of resin capsule bolting
- Resin bolting in stopes and development ends
- Fully mechanized support with bolters
- Conventional handheld bolting
- Improved safety aspects
- Future applications.

Appropriate resin bolting is introduced to improve the safety of our people and reduce production down time and increase production and productivity.

What is being discussed has been in practice and tested over many years in the coal mining industry and now has been accepted and is being used extensively in the platinum mining industry with good results. It is therefore prudent that this technology be passed on so as to ensure that the mining industry be a safe one to work in.

Introduction

When an opening is created in rock and the surrounding strata become unstable, it can be strengthened by various means of support to activate, conserve and improve the inherent strength (tensile and shear) of the strata and maintain their load-bearing capacity.

Support is defined as all methods which essentially provide surface restraint to the rock mass via installation of structural elements at the surface: timber props, steel arches, timber packs, mesh and sprayed material such as gunite/concrete. These are termed ‘passive methods’ of support as they rely on the rock mass moving to develop their resistance load.

In contrast, reinforcement is considered to include methods which modify the internal behavior of the rock mass by the installation of structural elements within it. Reinforcement methods are described as ‘active methods’ of support. These include tensioned point anchor bolts and resin anchored bolts. They are intended to react to rock mass movement, develop a restraining force and transfer that force back to the rock mass. This counteracts the driving force and eventually a balanced condition is reached when the total mobilized resistance within the rock mass is at least equal to the available driving force.

Resin-grouted Rockbolts offer advantage over expansion shell bolts in providing higher strength anchorage in weak or intensely jointed rock. They also perform more reliably than expansion shell bolts when subjected to blast vibrations. Resin bolts provide far greater anchor strength than friction bolts (split sets) which tend to fail in tension if they are initially subjected to shearing.

The purpose of underground rock support can be summarized as follows: ‘To control the movement of strata surrounding an opening in such a way that the availability of the opening to perform its designed functions is not impaired.’

History of resin bolting

The earliest examples of strata reinforcement date back to the primitive ‘Baiga’ tribes of India who strengthened weak ground by driving wooden nails into it.

The early twentieth century saw many isolated references to the use of rock bolt systems, but only in 1947 it was developed on an industrial scale. The USA was concerned about rising FOG accidents, thus prompting the reassessment of underground support.

By 1952, the annual consumption of bolts had risen to 25 million solely mechanical point anchored bolts.
It had spread to the UK but did not succeed due to weak strata and different mining methods.

Mechanical bolts do not work in weak strata due to the creep of the anchor head making the bolt ineffective.

This prompted research into embedding the bolt into a material introduced into the hole after bolt installation to prevent creep of the point anchor in the hole.

Synthetic injected epoxy resin was introduced to the USA in 1956.

Work began to get a system allowing the bolt and the resin to be installed in one operation.

1957 saw the first glass resin capsule system ('Klebanker') introduced in Germany.

Although this resin proved to be an easy and effective means of anchoring a bolt, it was limited by its high manufacturing cost.

The French further improved the system by encapsulating polyester resin in a plastic film.

Germany introduced the system in 1980.

Initially, point anchor bolts were installed and required tension in the bolt to produce a normal force between the layers of strata, increasing the frictional resistance in the rock.

Full column bolting offers a beam building approach with or without tension. The horizontal shear forces being resisted by the lateral stiffness of the grout/bolt combination.

The success of full column bolting as a support medium in weak ground in stratified deposits has increased, and in some cases is the only viable option for coal extraction.

Throughout the world, resin bolting systems have been accepted as primary support. The USA uses approx. 100 million bolts per year. SA uses 5 million approximately with 90% being full column. Australia uses 4 million fully grouted. Russia, India, China and Europe are major expansion areas at the moment (Minova guide to resin grouted bolts).

From 2003 to date, platinum has become the most exciting expansion area for resin bolting in the industry.

**Bolting theory with a focus on resin capsules**

Resin bolting actually reinforces the rock, improving the strength of the rock mass into which they are installed so that the rock itself becomes part of the support system.

Rock around mine openings and tunnels almost always fails in shear, either along joints and other planes of weakness or through the rock material itself. Typically, failure is driven by the rock stress field which is concentrated around the opening.

For rectangular openings, the horizontal stress component is concentrated in the roof and floor and the vertical component in the sides.

For circular openings, the resulting stress component can be visualized as a hoop stress surrounding the opening and are on the edges of the excavation (Figure 1 a.)

If this load exceeds rock material strength, shear failure occurs with shear displacement and lateral dilation of the failing rock (Figure 1 b.)

When a bolted tunnel or mine roadway fails in this way, the result can be seen in terms roof 'shortening', where the distance between the installed bolt ends across the roadway actually reduces, and roof lowering, causes the dilation of the failing rock.

Alternatively, shear may involve sliding displacement along preferentially oriented joint planes and other discontinuities.

**Rock bolts**

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 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 bolt types – 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. Adhesion plays no significant part in bond strength and it is wrong to think of resin-bonded bolts as being 'glued' to the rock.

Shear in the resin layer caused by the rock or bolt displacement generates high radial stresses which act across the interfaces and maximize the frictional resistance.

Both the bolt profile design and also the rifling of the borehole wall, as well as the resin properties are factors in generating this frictional resistance.

From 2003 to date, platinum has become the most exciting expansion area for resin bolting in the industry.
Polyester resin capsules such as the Minova Lokset® are the most widely used worldwide. These are supplied in a two-component capsule, easy to use and install. The installation involves spinning the bar through the capsule/s, breaking it and mixing the mastic and catalyst together. This mix hardens, fixing the bolt in the hole.

**Advantages of using resin capsules**

**Setting time**
- Flexible with working times (spin + hold) ranging from 15 seconds to 10 minutes
- Quick and fast
- Used as both primary and permanent support
- Effective within minutes—offers support almost immediately
- Does not restrict mechanization
- No shrinkage, in fact slight expansion on setting

**Pre-tension capability**
- The support design can be flexible for varying ground conditions e.g. end-anchoring in good ground to full column in poor ground (thus clamping the strata both horizontally and vertically) without changing products or equipment
- High stiffness of 70 kN/mm on 250 mm length
- High ultimate strength of ±28 MPa
- Shorter critical bond length
- 160 kN on 250 mm bond length (lab tests)
- Vaal Reef—170 kN on 450 mm *in situ* tests
- Supplied as a factory mixture thus no operator component proportioning
- Highest shear resistance of any support medium available
- Time deterioration is visible as capsules either become limp or harden
- With cement one cannot see the deterioration
- Resin gives the best corrosion protection as it encapsulates the bolt completely (if full column is used)
- Is cheaper per installation than mechanical bolts
- No bubbles or voids found in the resin
- It is not affected by water and can even set under water.
- Excellent quality assurance if used in accordance with the specifications
- Max hole length of 3 m for full column and can be used as an end anchor from 3 m – 13 m.

**Disadvantages of using resin capsules**
- They require a longer bond length.
  - If suspension design is applied as against Mechanical end anchor, but a shorter bond length than that for cement grouts
  - Critical bond lengths (minimum bond length of 500 mm in practice even though lab tests show results with shorter lengths)
- Higher cost per kg
  - More expensive than that of cement per volume at present.
- Parameters
  - Peak performance is obtained when used within a 5–10mm annulus. Minova has done extensive tests in their own lab as well as with CSIR in larger hole diameters showing that even this problem can be overcome.
  - Here are actual results obtained from the CSIR tests done in May 2008 with Minova 30sec Lokset ‘A’ resin to see the effect of annulus on pull tests results.
  - Results
    - 32 mm hole = 20.80 tons on average
    - 34 mm hole = 16.10 tons on average
    - 36 mm hole = 14.50 tons on average

![Figure 1b. Concept of stress driven shear failure for rectangular and circular (hoop stress) section openings](image)
• Minova in-house tests were done on the deflection of a 20 mm bar in a 27 mm hole and there was only 1.67 mm deflection at 150 kN.
• Many extensive tests have been done and are available on request.
• The type of deflection plays a big role in the results obtained on pull out and deflection.
• There are numerous bolts on the market that can be used effectively with resin grout. Before adopting a bolt it is advisable to contact the resin supplier to ascertain that the bolt type is effective for resin bolting.
• Mixing of the resin in-hole is critical and gloving must be prevented.
• In larger diameter holes a bolt with a wave (wiggle) can be used with good results with resin. It is however always the best practice to drill the smallest diameter hole possible.
• Hole length is not to exceed bolt length.
  – Take into account washer and nut thickness as well as 20 mm of thread protruding.
  – There are also bolt designs to consider eg. nibbed bar or forged head bolts where the effective bolt length is shortened.
• Controlled good mixing is required.
  – Here Minova has done extensive tests as well. With the 70:30 resin to catalyst ratio this has been overcome to a great extent and continuous tests are being done even now regarding this. These results are also available on request
  – A rotation speed of 100–750 rpm is ideal. Minova has done tests that have shown that even >50 rpm has worked well with their resin.
  – High rotation speed shortens the set time. On-site tests should be done if speeds exceed 400 rpm.
  – When using a jackhammer use slower setting resin, usually 60 s (green) or 120 s (blue). Spin for 40–60 revolutions. A good machine spins up to 125 rpm (depending on the compressed air available).
• In a two-speed resin system, the shorter spin time determines the set time.
• Shelf life
  – Resin has a 6-month shelf life @ 20°C whereas cement has a 12-month shelf life (in dry conditions). If the temperature is excessively high, underground storage should be done or air-conditioned containers on surface should be used, as seen below.
• Temperature sensitive
  – Minova has designed a resin that does not have creep even at temperatures of 60 degrees celsius. Ongoing tests are being done continuously so as to make the best product available for all your needs.
  – Now temperature is not a problem either.
• Can be used with Shepherd’s Crook as long as the bolt gets spun to allow for proper mixing
• No effective lacing eye is available.

As can be seen, the advantages far outweigh the disadvantages, so why not resin?

Resin bolting in stopes and development ends
• Conventional narrow vein in-stope support methods still result in injuries. Falls of ground are still a major contributor to in-stope injuries in our mines. The question is: how do we reduce injuries? Are we using the most appropriate support technologies available today? How much do we have to spend to make our mining environment safe?
• Conventional temporary support such as elongates have their limitations. We use either permanently installed sticks or typical jacks installed and removed, but the removal process poses a safety risk. These units could hamper in-stope movement and productivity.
• We must find safer mining methods and implement these.
• We support our stopes for the safety of our people.

Current conventional narrow vein in-stope support is as follows
• Temporary support by mechanical props or jacks or temporary, support by timber sticks, followed by:
  – Permanent support by timber packs or cement packs or pre-stressed profiled elongates.
• Issues with this method are:
  – There are two support cycles i.e. temporary followed by permanent.
  – Low productivity.

<table>
<thead>
<tr>
<th>Hole ID (mm)</th>
<th>Bar diameter (mm)</th>
<th>Capsule diameter (mm)</th>
<th>Bond L (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>32</td>
<td>20</td>
<td>28</td>
<td>300</td>
</tr>
<tr>
<td>34</td>
<td>20</td>
<td>32</td>
<td>300</td>
</tr>
<tr>
<td>36</td>
<td>20</td>
<td>32</td>
<td>300</td>
</tr>
</tbody>
</table>
RESIN BOLTING IN SOUTH AFRICAN PLATINUM MINES

– Support medium must leave a path for the scraper to move.
– It is bulky and adds to logistical problems to get it on site.
– People are exposed to unsafe hanging wall.
– The support cannot be placed right at face.
– Support has a low stiffness.
– Falls of ground still occur even where bolts are installed.

The Autorock System of roof support is currently being used extensively on the platinum mines. This system lends itself to the use of good quality resin installations.

In-stope roof bolting using an Autorock drill rig with resin offers a safer drilling and installation method of support and roof bolting becomes a permanent installation as resin offer immediate permanent support.

The rig is a small lightweight roof bolt drilling machine designed for in-stope resin roof bolt drilling and installation. It can be used with bolts of various types.

It is fast drilling and has good rotation and excellent thrust.

The stroke of the machine is 10 cm less than the overall height of the machine and the size ranges of the machines are from 750 mm to 5 m.

Rock drill types that can be used in the Autorock are: compressed air percussion, electric, hydropower or hydraulic. Various size rock drill units can be fitted to the Autorock.

Autorock drill rigs are a two-man operation and can be operated remotely for most of the time thus improving the safety of our people, reducing production down-time thus increasing production and productivity.

With the operator working remotely he experiences reduced noise levels as well as the carpal syndrome experienced with jack hammer vibration. Furthermore, the operator is away from the unsupported face area.

The installation of resin grouted roof bolts as temporary and also primary support in-stope on and at the face result in improved safety with fewer rock falls due to good coverage of the area. This offers a flexible support pattern when needed.

Another benefit is the fact that no additional temporary support is required as the Autorock has built-in temporary support jacks in the machine.

Furthermore the face area is left clear for people and equipment to manoeuvre.

Resin bolting bonds together broken and fractured rock
into a thicker beam and requires no re-tensioning as is the case with mechanical anchored bolts.

There are a large range of resin products available for use with the Autorock and other methods of resin support that could be tailor-made to suit your requirements. These will be explained.

**Fully mechanized resin support with bolters**

- Resin bolting as mentioned lends itself to all types of mining systems and conditions. Mechanization and resin go together like a hand in a glove. As you are aware now, resin has been perfected to such a degree that it is favorable for almost all. With this in mind, why go for a system that is less user-friendly and effective. Once again, resin can be tailor-made to offer you the best system for your requirements.
- In stope bolting has made it possible for machinery to access the stope face previously populated by dense forests of conventional stick support.
- In 2002-2003 Extra Low Profile trackless equipment was introduced into the platinum mining operations. With this introduction, the use of resin can now be implemented as well and with the result this method of support is constantly growing. The Autorock system can also be implemented here.
- This mechanized system therefore requires a support system that has the capability to match the production output. Tests were done on a number of sites onboard and pillar and breast mining operations. The machines demonstrated an adequate level of mobility, providing the face area is clean and there is not an uneven footwall and hanging. With resin rock bolting, there are no obstructions in the way of such machinery.
- Remote control operations for roof bolting has enhanced safety as the operator does the installations from a safe position under resin supported roof, giving him/her more freedom to observe the hanging wall during such installations.

Even if the insertion of the bolt and resin is done manually, there is still a greater degree of safety than when compared to hand-held drills and grout operations. To improve safety even further, the use of resin injectors with parachutes and top hats may be used. With this method, the operator can insert the resin into the holes remotely as well.

- Mechanization in conjunction with resin gives higher quality bolting even in a confined stoping horizon. The ability to install bolts perpendicular to the hanging wall offers maximum penetration and so resin and the prestressing capabilities that this system offers makes for a more effective support unit.
- Mechanized bolting with resin brings about better working conditions for the operator due to cement burns and mess, reduced risk, and improved ergonomics and to add to the improved product, a higher morale of the operator.
- Rotary bolting is a definite option even though penetration is slower than the rotary percussion units. The lower front end drill mechanism provides the opportunity for even lower mining heights.

The Autorock bolter makes use of percussion, but with the new design technology can be used in these lower mining heights (stopping widths of as low as 700 mm).

**Conventional hand-held (jack hammer) bolting**

- There are many mines that still use this method of bolting and do so with good results.
- One needs to look at the hole size and adapt the tendon used as well as the machine used and its performance.
  - Much of the information regarding this has been covered earlier in the paper under the heading “Resin bolting in stopes and development ends”.
  - With the extensive technology available, even this type of bolting is also effectively done with resin (as mentioned earlier in the paper using large diameter holes). As always, it is advisable to be in consultation with the resin supplier when implementing the system.

**Improved safety aspects**

- Minova has quality management systems in place covering all aspects of the production and implementation of the resin bolting system to ensure that what you get and use is of the highest quality.
- There are other systems in place in the industry, but they all have limitations and are discussed briefly below.

**Mechanical anchor steel tendons vs resin**

- The mechanism in which this bolt works limits their use to fairly hard rock conditions.
- Reliability depends on the amount of torque applied when installed.
- The bolt can lose tension through vibration after blasting.
- Corrosion may also occur where the rock contains water.
- This bolt is generally expensive in fact resin bolting is cheaper
- Resin overcomes all these aspects with improved results and safety

**Friction bolts (split sets) vs resin**

- Widely used in the hard rock mining industry where there is a high degree of bolting and the rock strata is suitable for this system.
- Works by utilizing the friction generated between the strata and the bolt.
- Should not be used for long-term support, unless protected from corrosion.
Being friction-bonded to the entire length of the hole it can be classified as a stiff support. But as it cannot be tensioned it is actually a passive support system.

Resin once again is the more favourable method with more than favourable results.

Friction bolts (swellex bolts) vs resin

The principle of operation is that having drilled the required diameter and depth hole, the bolt is installed and a pump is used to expand the tubular bolt radially with water (or other incompressible liquid) at high pressure.

There is a cost involved in the pump acquisition and if the pressure load pipe breaks off, the pressure is lost and the bolt is worthless.

Present applications of resin available

The implementation of a Two Speedie resin system where there are in effect two speeds in a single resin capsule ensures that the correct amount of resin capsules are used in the installation thus preventing operator inadequacy are also available.

There is the “Smart Bolting” Spin to Stall system available too, but this to date could only be used in mines where the bolting equipment is of high standard and the temperatures are in the temperature range less than say 23°C. Minova has at present done research and development into overcoming this and it is now available to the warmer mines too.

To measure movement within the roof there are Telltales available. There is the rotary-type which can be used in higher areas and the bobbin-type that can be used in lower stopes. See below.

Future applications

Minova RSA is currently looking at the Quick-Chem

![Figure 7. Mechanical bolt](image1)

Figure 7. Mechanical bolt

![Figure 8. Friction bolt (Split set)](image2)

Figure 8. Friction bolt (Split set)

![Figure 9. Swellex bolt](image3)

Figure 9. Swellex bolt

![Figure 10. The Quick-Chem inserter tube together with resin capsule](image4)

Figure 10. The Quick-Chem inserter tube together with resin capsule

![Figure 11. Using the face drill to drill holes for resin bolting to be used with the Quick-Chem system](image5)

Figure 11. Using the face drill to drill holes for resin bolting to be used with the Quick-Chem system
System of bolting where the Jumbo face drilling machine can be used for bolting as well. This system is currently in use in Australia, supplied by Minova Australia.

Another new product available is the glass reinforced product (GRP) bolts. Traditionally, these products have always been priced well above that of steel bolts. The way that the steel prices are going, this type of support medium, used together with resin is becoming favourable. The collieries are starting to use them for sidewall support and are even looking at using them for their main support.

GRP bolts are totally non-corrodible and have strength comparable to steel bolts. They are cuttable as well as flexible so can be used in low stopes where longer bolts are needed. They can be supplied hollow for grout injection too.
RESIN BOLTING IN SOUTH AFRICAN PLATINUM MINES

Table II
The properties of a GRP bolt as against other type bolts

<table>
<thead>
<tr>
<th>Property</th>
<th>GRP</th>
<th>Steel</th>
<th>Aluminium</th>
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</thead>
<tbody>
<tr>
<td>Specific weight (kg/dm³)</td>
<td>1.9</td>
<td>7.8</td>
<td>2.7</td>
</tr>
<tr>
<td>Tensile strength (N/mm²)</td>
<td>1 000</td>
<td>600</td>
<td>350</td>
</tr>
<tr>
<td>E-Modul (N/mm²)</td>
<td>44 000</td>
<td>207 000</td>
<td>69 000</td>
</tr>
<tr>
<td>Ultimate strain (%)</td>
<td>2.5–3.5</td>
<td>&gt;10</td>
<td>&gt;10</td>
</tr>
</tbody>
</table>

Figure 17. GRP bolts are developed for strata support in mining and tunneling and for slope and face stabilization. The GRP bolt can be trimmed if needed. It has a high ultimate load. The cuttability protects machinery and equipment and prevents damage to machinery (Mainly stooping in coal mines). GRP bolts are well suited as permanent support.
Conclusion
Resin bolting is a first world technology and the use of it can lead to the mines creating a safer working environment for all its workers.
Resin bolting with all the development, has become a user-friendly method of ground support and stabilization and should be the first choice of support medium wherever possible. Minova is a company that is directed at not only supplying high quality support systems to the industry, but also partnering and thereby ‘Delivering the Promise’.

Acknowledgements
ARTHUR, J. and TAYLOR, J. Status-quo, Opportunities and Challenges of Mechanized Roof Bolting.

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Sales Manager, Minova RSA

- 31 years Mining experience – 8 years (1977-1985) with Gencor (Miner; S/Boss)
- NDT (Coal Mining) 1977-1980
- Started with Minova RSA in March 1985-Sales Marketing
In the position of area manager and currently sales manager of Minova RSA
In this time I have worked with BHP Billiton, Anglo Coal, Exxaro, Sasol, Rio Tinto, Xstrata, Grinaker, Total Coal and Numerous other Mining companies.
Many years of SME (subject matter expert) training at I-Campus; CTC and De Beers