A PERSPECTIVE ON UNDERGROUND SUPPORT TECHNOLOGIES IN SOUTHERN AFRICAN PLATINUM MINES TO REDUCE SAFETY RISKS AND ENHANCE PRODUCTIVITY

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Abstract

Falls of ground (FOG) still account for around 35 per cent of all fatalities in underground southern African mines.

To help reduce FOG, appropriate support technology needs to be implemented, and a mindset and cultural change are required to make a significant change. Discipline plays a major role and needs attention, whilst appropriate first-world support technology is available to assist in the reduction of injuries and the improvement of productivity.

Section 54 mine stoppages due to FOG are costly. Appropriate support should reduce these unnecessary stoppages.

Coal mining has adapted leading support technologies over the years. Platinum and chrome mines have shown significant moves towards adopting leading and appropriate support technologies, seeing noteworthy changes in injury statistics for the better.

In typical conventional underground mining operations, the use of temporary support components offers some protection to workers while the permanent and generally more elaborate support systems are installed or constructed. Nonetheless, FOG continue and still result in injuries to people.

The author wishes to explore the options and practicality of making use of new-generation support products and technology to provide not only safer support operations, but to also enhance productivity at the working faces.

This paper will examine the use of appropriate support technology as a means to making the working stope or development end a safer and more productive workplace.

South African mines safety status

In order to help reduce falls of ground (FOG), appropriate support technology needs to be implemented. First-world support technology is available and should be implemented throughout the industry where appropriate. In-stope bolting is practised on certain mines and not on others, and in most cases inflatable friction anchors are used in preference to full-column resin bolts along with suitable bolting rigs, which are not removed until the bolt installation is completed. It is preferable to have a support system in place that offers a more foolproof system of drilling holes and installing bolts, such as is offered by a resin bolt system. Furthermore, a mindset change to accept and implement best technology and available practice, along with improved discipline, is required to make a significant difference in our platinum mines. It becomes vital to accept that best technology and practice will lead to improved safety, and commensurate with this, improved productivity and output offering acceptable payback.

Work stoppages by the Department of Mineral Resources (DMR) in terms of Section 54 of the Mine Health and Safety Act are costly, and appropriate, and better support methodologies should reduce this waste as will become evident in the paper. As Section 54 stoppages are generally due to 'non-compliance', implementing the best practical and close–to-foolproof support systems, along with system built-in discipline, should result in reduced stoppages and enhanced safety and production.

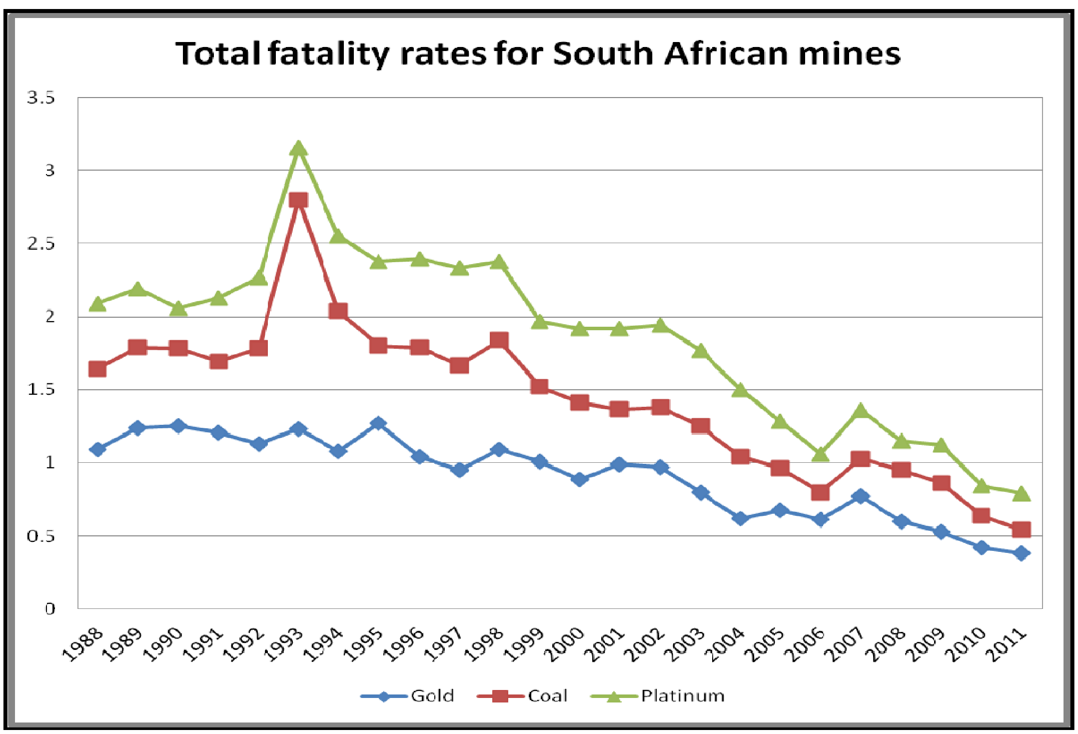

Figure 1-Total fatality rates for South African mines

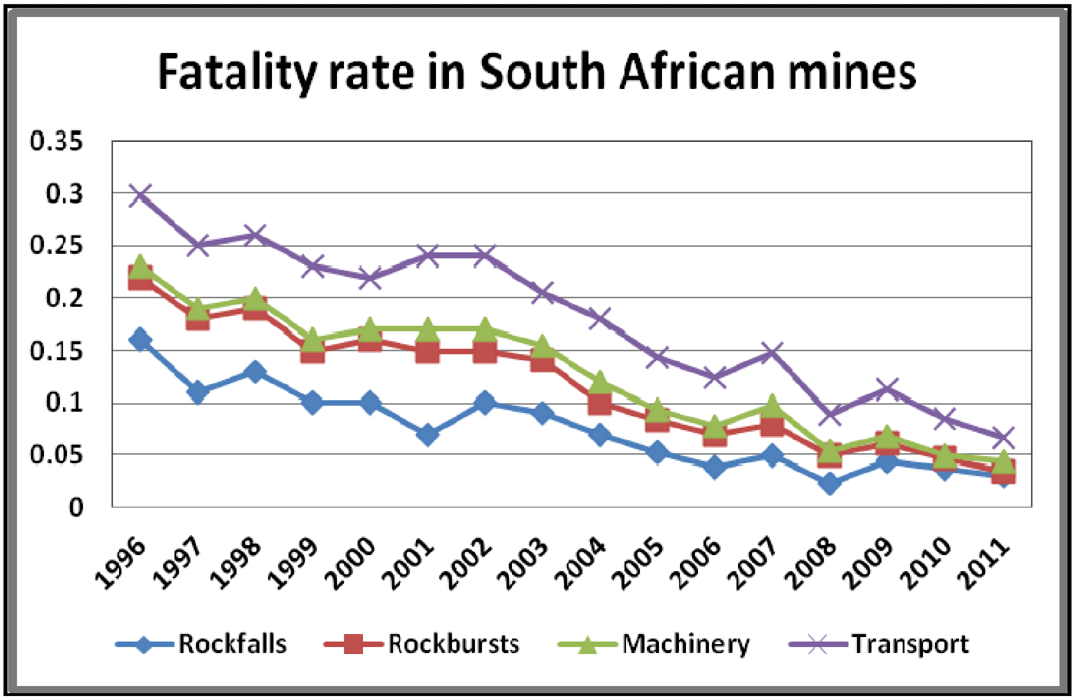

Figure 2-Fatality rates for various accident categories in South African mines (rates are generally improving but still not on 2013 milestone targets)

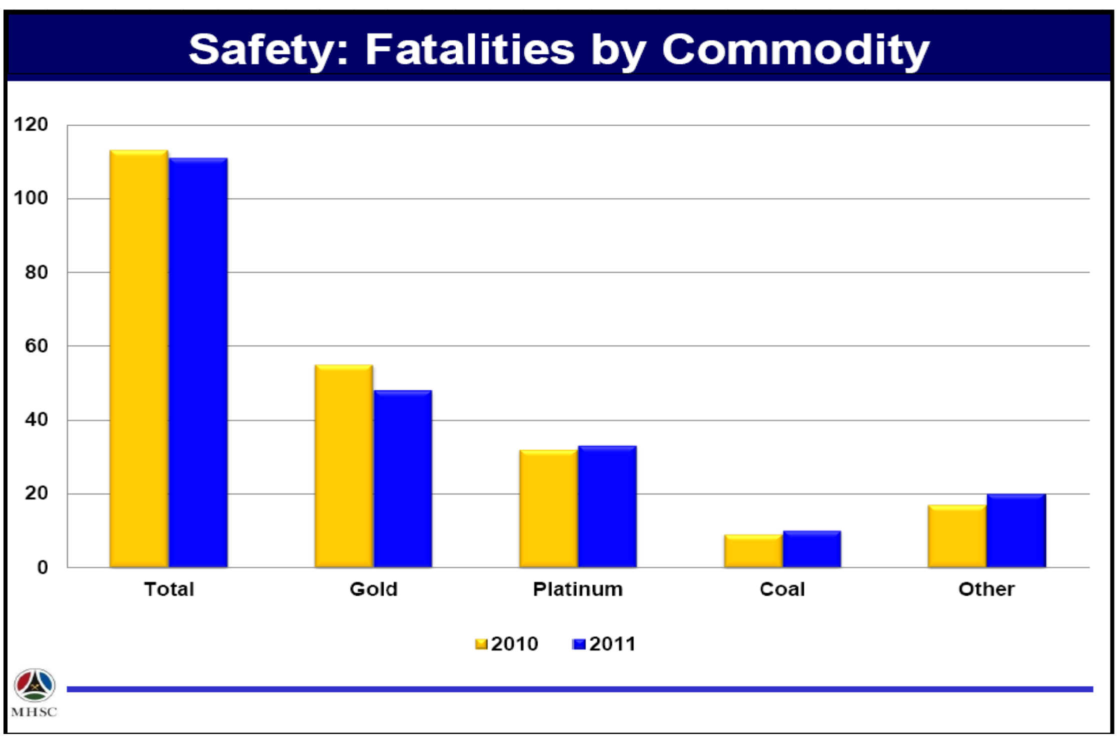

Figure 3-Number of fatalities per commodity sector, showing an increase in the platinum industry

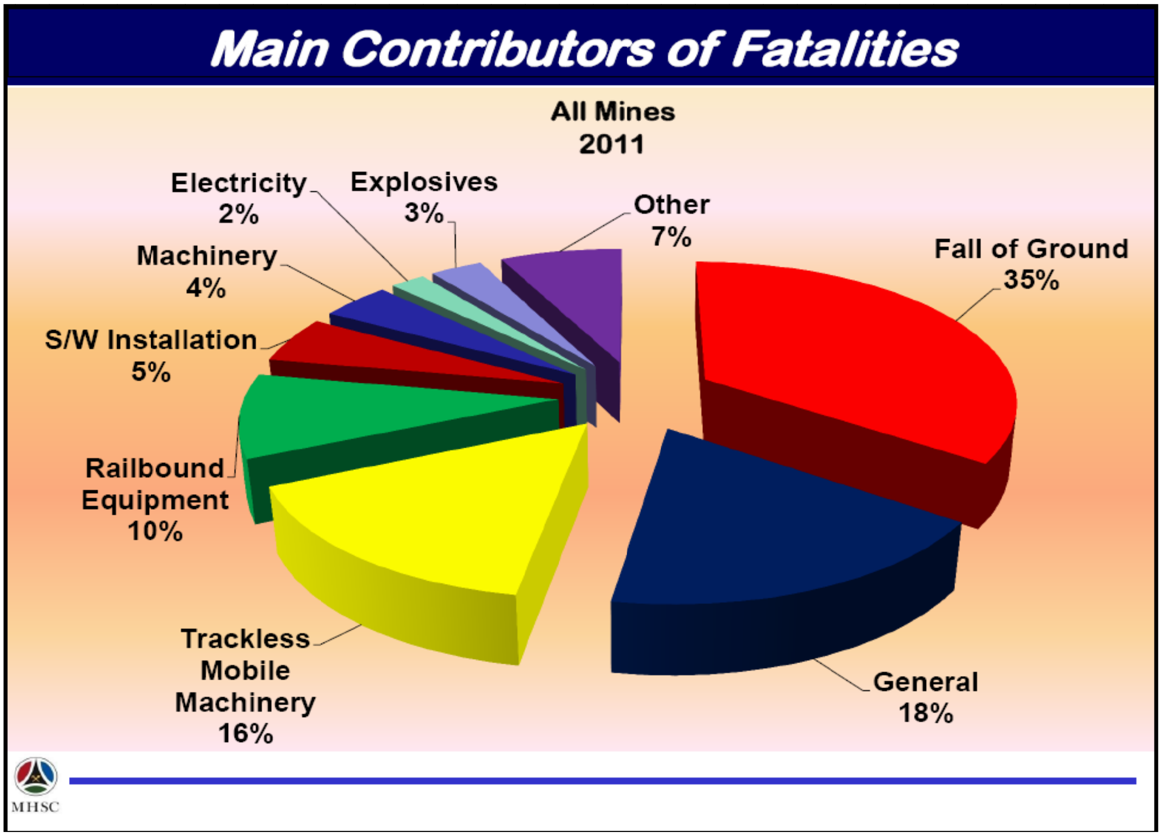

Figure 4-Main contributors to fatalities for all mines

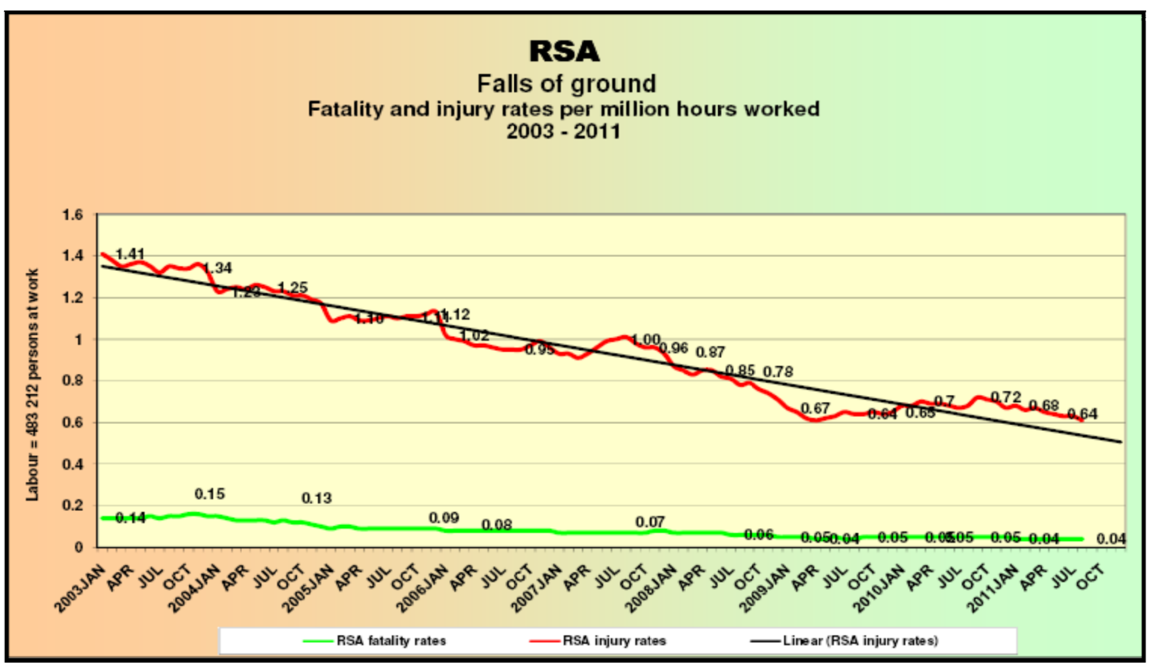

Figure 5-FOG accident and fatality rates for all mines, 2003–20011

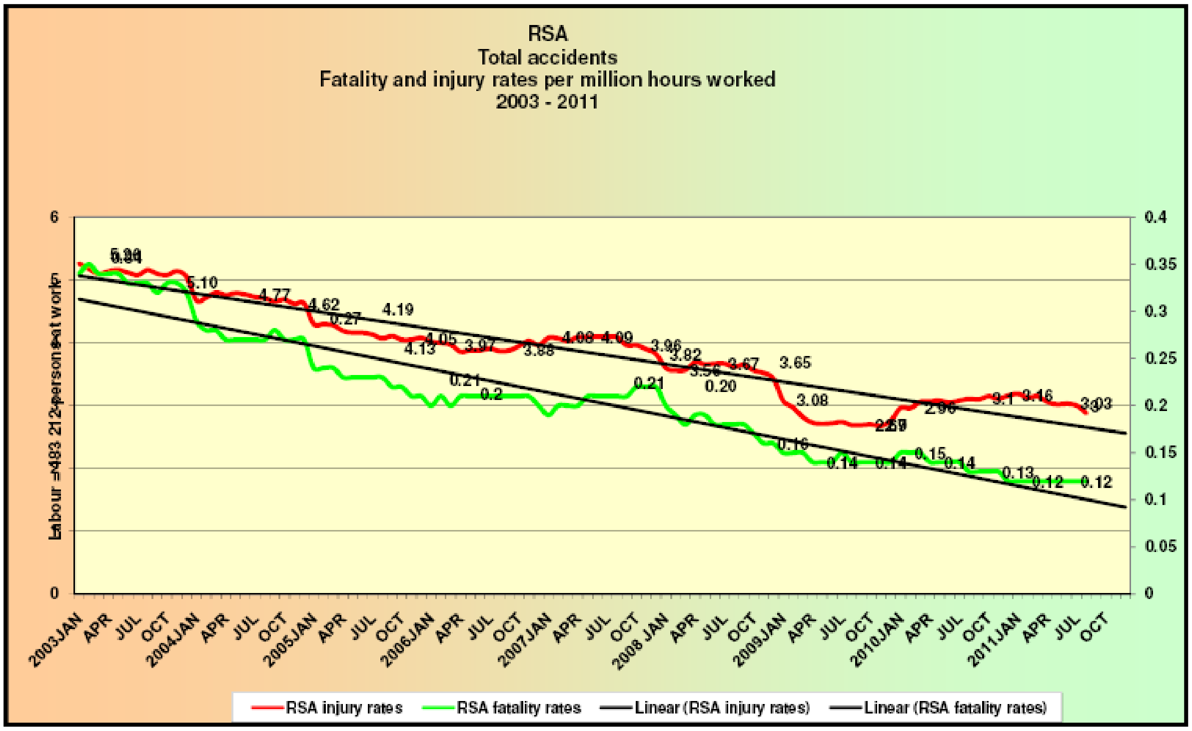

Figure 6-Accidents statistics for all mines (Even though we see a decrease in rates, much work is still to be done to meet 2013 milestone targets)

Current underground support principles in general

FOG are the major contributor to injuries and fatalities on South African mines with 35 per cent of all injuries, (Figure 4).

The coal mining industry has adopted leading support technologies over the years. This includes use of full-column resin capsule steel bolting with fast and slow setting resin in the hole, which allows for an immediately tensioned bolt. The bolter is removed from the bolt position only once installation is completed. Further improvements in full-column resin bolting currently implemented are spin-to-stall resin technology along with two-speed resin capsule and bolt installations. All of these contribute to an almost foolproof bolting system.

Platinum and chrome mines have made considerable progress towards adopting leading and appropriate support technologies, especially in the stoping horizon where rockbolts, accompanied by netting, are being installed up to the stope face before the next blast. Resin bolting in-stope is not common yet, nor is it common support practice in development ends. There is thus room for improvement in the adoption of such practice.

Gold mines are generally lagging in the adaptation of leading and appropriate support technologies, especially for in-stope support. In fact, very limited in-stope bolting is practised in gold mines, more than likely due to friable hangingwall conditions, hangingwall closure rates and perhaps the higher rock stresses due to depth. Development ends are generally not supported by resin bolts, which suggests an opportunity for improvement in the application of full-column, fast setting resin bolting.

Bolting systems currently in use in the South African mining industry are:

- End-anchor mechanical expanding shell steel bolts – these are used less and less in our mines. This bolt loses tension in friable ground conditions when the ground around the washer becomes dislodged, and leaves a loose bolt offering no support at all
- The above bolting system can be improved by post-grouting, making it a full-column bolt installation and consequently substantially more secure
- Splitset friction bolts offer frictional resistance and are generally limited to pullout resistance. These bolts offer good temporary support in competent ground. This system is cheap and easy to install with mechanized equipment
- Inflatable friction bolts, commonly known as 'Hydrabolts' or 'Swellex' bolts, offer improved frictional resistance but with limited pullout resistance. Here is another easy-to-install system. Installation of the bolt could take place well after the hole has been drilled and a rig has been removed, which means support is not immediate and work could continue under unsupported ground
- Shepherd's crook bolts have been used for many years together with full-column slow setting cementitious grout. This offers non-active support and should rather be used as secondary support if required. One should preferably install permanent and active support on the face and avoid having to carry out secondary support operations. The stiffness of the bolting systems is a requirement of the stress environment and might even require a yielding instead of a stiff system
- Then there are other cementitious grouted bolting systems offering various support regimes. These include 'GV' bolting systems. Generally speaking, cementitious grout is slow setting compared to resin and requires many hours and days before it offers long-term support
- Flexible cable anchors of various types, including mechanical end anchoring, with cementitious full-column post-grouted systems, are also available and in use.
- Polyester resin capsules used with steel bolts, breakout nuts, load indicators, special washers, and spin-to-stall two speed resin in one-capsule systems offer superior support, as these can be installed only while a rig is still in place offering support resistance. There is immediate load on the bolt - every installation offering immediate support, before the rig is removed, which may not happen with other systems.

Current underground support principles in coal mines as a baseline

Coal mines use mainly steel polyester resin capsule bolting systems. Commonly, 20 mm diameter, 500 MPa steel bolts are used. Small support holes ranging from 22.5 mm to 27 mm diameter are drilled for resin bolts.

Bolt and hole configuration offer good and close-to-optimum resin bolt installations. Bolts are end-anchored with fast resin capsules then tensioned to requirements. Fast resin capsules range from 15 second 'spin-to-stall' technology to slower 'spin and hold' technology. Bolt shear pin and load indicators, together with the best 'spin-to-stall' resin, offers virtually foolproof rockbolt installations.

Figure 7-Typical coal mining roof bolt support operations

Current underground support principles in hard rock platinum mines

As a result of the different mining methods applied in platinum mines, a wide variety of support items is used. Mechanized mining operations tend to use resin bolting, but other support items are also used. Various elongated timber support types are used, as well as a combination of timber and cementitious grout packs.

Narrow-vein conventional platinum stoping operations tend to rock bolt the stope hangingwall with any one of the different types of support items. Conventional development ends are generally supported with steel bolts and either cementitious grouts or resin capsules and friction bolts.

Generally, larger support holes are drilled than in coal mines, ranging from 28 mm to 36 mm diameter for steel bolts. Hand-held drilling is customary, with relatively little mechanization. Rotary percussion drilling is the norm. Most often the same drilling equipment and accessories are used to drill both blast and support holes; hence the larger support holes.

Commonly 16 mm to 20 mm diameter 500 MPa steel bolts of various configurations are used with resin capsules. Bolt and hole configurations, i.e. larger than 32 mm holes, do not generally offer good resin bolt installations. The holes are too large for the bolts to offer a bolting system similar to that used in coal mining.

Bolts are end-anchored with fast resin capsules then tensioned to requirements. Fast resin capsules range from 20 second 'spin-to-stall' technology to slower 'spin and hold' technology with hand-held or mechanized machinery.

On the whole, support installation discipline is inconsistent due to the complications of multiple resin capsules and both spinning and holding time of the resin, and this requires improved systems that offer consistency with every installation.
Bolt breakout nut with shear pin and load indicators, together with best 'spin-to-stall' two-speed resin in one capsule, called TOOSPEEDIE® resin, offers close to perfect rockbolt installations.

Figure 8-In-stope bolting as it was frequently done in the past, with a make-do drilling system and no apparent temporary support or clamping systems installed with the drilling

Figure 9-Typical gold mine temporary support with good backfill close to the face – no bolting

Current underground support regimes: various steel bolts

The resin steel bolt with a resin grout consists of a deformed bar stud, nut, and bearing plate (washer). The bolt is grouted using resin capsules. (A grout is a general term for the matrix around a bolt or cable anchor, and could be a cementitious grout or a resin grout)

Cementitious grouting of various types of steel bolts is commonly used in development ends in hard-rock mines. The quality and setting times of the cementitious grout can vary greatly.

Long anchors of various types, lengths, strengths, and diameters are used for different and special applications.

Friction bolts are also used, and these include splitsets, Hydrabolts, Swellex, and end-anchored mechanical shell bolts.

Potential future support regimes: polyester resin capsule rockbolting

Resin capsules used with steel bolts offer excellent rockbolt support almost instantly.

Spin-to-stall resin capsule technology is proven at correct hole and bolt diameters with the correct resin. Spin-to-stall shortens operation cycle time and ensures correct torque and installation without over- or under-spinning.
TOOSPEEDIE® i.e. fast- and slow-set resin in one capsule ensures full-column installations all the time. (TOOSPEEDIE® is the trademark for two speeds of resin packed into one capsule).
Soft or smooth resin offers less insertion resistance, making hand-held installations easier than when using coarse resin capsules. Drill rig drilling and installation facilitates the operation cycle even more.

Potential future support regimes: small hole drilling

Small hole drilling, in both coal and hard rock, opens the door to more effective drilling, better support quality, and cost-effective support systems. Small hole drilling in coal is typically 22.5 mm and makes smaller than 20 mm diameter steel bolting with resin possible. This hole size, with a specially formed steel bolt, makes a 18 mm or even a 16 mm bolt diameter a reality.

Small hole drilling in hard rock is typically 25 mm for one-pass bolts and holes and 28 mm for coupled steel drilling and coupled steel bolts. Consideration should be given to a dedicated drilling and installation system for greater success. Some drilling at 25 mm diameter has been done in quartzites and in chrome and platinum mines, and has proven a viable and practical solution.

Large-scale drilling at 25 mm diameter is about to be rolled out on some mines as it has the potential of improved bolting systems, as well as cost savings due to the smaller holes, smaller bolts and drill steels, and faster drilling.

It goes without saying that the hole size must match the size of the support bolt.

Support drilling and bolt installation equipment is designed for support optimization and should be considered over the use of blasthole drilling technology. Small hole drilling with small drill steel of 19 mm diameter, should be conducted with a dedicated rig rather than standard hand-held drilling equipment. The full 25 mm bit along with a 19 mm drill steel system is available and should revolutionize drilling of support holes and support items that work with small holes in hard rock.

Potential future support regimes: thin spray liners

Thin spray liners (TSLs) of various types and characteristics and from 4 mm to 8 mm in thickness are applied to rock surfaces to control key block failure and assist in localized support. TSLs offer a high-strength quick-setting product to facilitate early support and thus improved operation cycle times at optimal safety.

TSLs are available with high bond strength even on coal surfaces. Quick-setting TSLs offer 10 MPa UCS 2 hours after application. The ease and speed of application of TSLs is an advantage over shotcrete application, and lightweight equipment allows for ease of transport. All in all, the use and application of TSLs eases logistics greatly when compared to shotcrete. Surface preparation remains important, as with shotcrete, and good scaling and washing down must be the norm for success.

TSLs can complement shotcrete as an easy, immediate, and early application followed later by shotcrete spraying, as shotcrete bonds very well with a good TSL and the end result could reduce the overall TSL and shotcrete thickness while offering the same support. Shotcrete subsequently offers more structural support applied at thicknesses of 50 mm and more for appropriate strength.

Table I-TSL product characteristics and comparisons

Description	**Time**	**Shotcrete** (≈25 mm) 25 MPa	**KT 2C** (≈5 mm) 3 m^2	**KT White** (≈5 mm) 3 m^2	**KT Grey** (≈5 mm) 3 m^2	**KT Fast** (≈5 mm) 3 m^2
Compressive strength (MPa)	2 hours	Not tested	8.9	-	-	9.9
	24 hours	Not tested	14.4	17.3	6.3	18.9
	7 days	Not tested	20.9	31.1	21.5	20.6
	28 days	Not tested	35.2	44.8	32.5	29.2
Tensile strength (MPa)	2 hours	Not tested	1.9	-	-	0.75
	24 hours	Not tested	2.4	1.4	1.6	1.4
	7 days	Not tested	2.7	2.2	2.8	1.9
	28 days	Not tested	4.7	3.1	3.1	3.5
Shear strength (MPa)	4 hours	Not tested	2.85	-	-	7.91
	12 hours	Not tested	3.81	-	-	10.45
	24 hours	Not tested	4.32	6.93	5.42	11.91
	7 days	Not tested	6.68	13.93	9.04	11.91
	28 days	Not tested	8.2	10.93	9.42	17.95
Shear-bond strength (MPa)	24 hours	Not tested	-	0.91	1.49	-
	7 days	Not tested	4.8	1.65	2.09	2.78
	28 days	Not tested	6.3	1.65	2.09	3.19
Yield (litres)	-	N.A.	13.5	14.9	15.5	17
Pot life (min)	-	Long	40	60	60	45
Setting time @ 25°C (h)	-	Long	1	2-3	2-3	1
Rebound	-	Poor	Hardly any	Hardly any	Hardly any	Hardly any
Bags per m^2 kg per m^2	-	3.5 88	0.33 8.35	0.33 8.35	0.33 8.35	0.33 8.35
Ease of Application	-	Cumberso me	Easy	Easy	Easy	Easy
Time to cover 45 m^2 (conv application)	-	150 minutes	55 minutes	55 minutes	55 minutes	55 minutes
Equipment	-	Large	Small	Small	Small	Small
Interference with dev cycle	-	High	Minimal	Minimal	Minimal	Minimal

(One square metre of KT Fast 2C TSL sprayed on paving bricks 4 mm thick tested at CSIR carries 1360 kg point-loaded with a 458 mm round plate)

Figure 10. - Typical TSL application and equipment

Potential future support regimes: GRP bolts and Powermesh (FiReP®)

Glass reinforced Plastic (GRP) is an alternative product to steel and can be used as bolts or mesh in place of steel.

The benefits of FiReP® bar are:-

- High corrosion resistance
- Excellent cuttability
- Continuous threaded profile
- High tensile strength
- Greater flexibility than steel
- Lightweight
- Wide range of dimensions and diameters
- Improved logistics – reduced transport cost per unit
- Very easy to handle

The disadvantages of GRP are:-

- More costly than standard steel bolts or mesh
- Not blast resistant and quite brittle i.e. will bend to a point and then break the resin compound leaving fibre strands
- Shear strength is at least half of that of standard steel
- Not yet locally produced
- To offer bolt strength resistance, the nut becomes large and is also relatively expensive.

GRP bolts and mesh can be used in normal applications in place of steel, provided installation is good, reducing blast damage. A 20 – 30 per cent increase in cost (over steel bolting) may require that it be applied only where its specific properties are needed.

Potential future support regimes: steel mesh

Mine steel mesh provides surface support coverage to loose rock between installed rockbolts in underground mining excavations. Multiple configurations of mesh are available, including variations in sheet size, aperture, wire diameter, and black or galvanised wire. Different mesh products are specific to metalliferous and coal mining requirements.

Steel mesh provides

- Good control of FOG, but leaves small apertures for small rocks to dislodge
- Safety improvement; creates a safer working environment under strong flexible coverage
- Ultimately improved productivity with fewer or no FOG and consequently fewer stoppages in the workplace with re-opening or re-establishing the face
- Improved gully and face hangingwall conditions as the rock is held in its key blocks.

Figure 11-Steel weld mesh installed with improved ground conditions

Potential future support regimes: various steel bolts

Steel bolts used in South African mines are generally of 500 MPa material. Higher quality steel bolts of typically 600 MPa and more are available and could be used in smaller drilled holes where the bolt diameter is reduced to less than the common 20 mm diameter bolt to sizes of 18 mm and even 16 mm. These increased MPa steel bolts offer excellent shear strength with somewhat increased stiffness. These higher quality steel bolts of smaller diameter, along with a profiled bolt shape, will equal or better the support offered by standard 20 mm resin bolts in relatively large support holes. The proposed bolt profile to improve resin mixing and improved pull out strength is the Secura Bolt™.

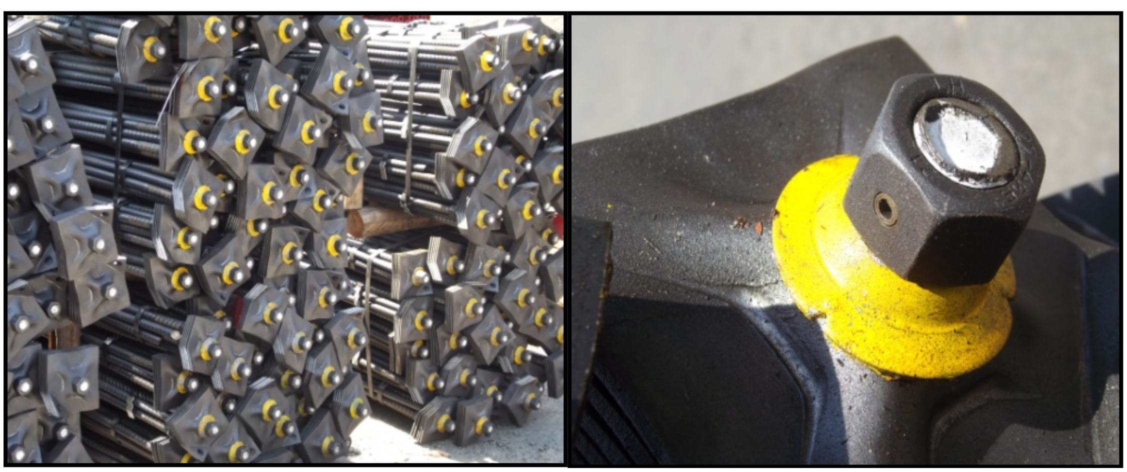

Figure 12-Typical steel bolts bundled as well as breakout nut, (shearpin in nut), load indicator, and appropriate washer

Potential future support regimes: in-stope drill rig

The patented double-clamping Autorock in-stope drill rig has revolutionized narrow-vein vertical support hole drilling for in-stope support in South African platinum mines since its introduction in 2001. Other manufacturers' versions of in-stope drill rigs followed, and numerous in-stope drill rigs have been introduced to the platinum mine stope faces. Semi-mechanized small drill rigs make rockbolting in narrow stopes a viable proposition by combining safe operation, accurate drilling, and high output, all at a fraction of the capital and operating costs of fully mechanized rockbolting rigs. Other drill rig units in the market with one clamping cylinder or no clamping cylinder i.e. clamping the rig to the hangingwall to allow for rigidity while drilling and improving drilling and jumper changing times, are also used. The double clamping system offers improved clamping and some support resistance. The Autorock rig itself offers up to 30 kN of static load resistance.

Small hole hard rock drilling is proposed with rigs with clamping facilities, only where the 19 mm drill steel is thrusted vertically or near-vertically and perpendicular to the rockdrill. It is initially to be used with pneumatic rockdrills on a rig drilling with 25 mm or 28 mm bits. Where coupled drill steel is required, drill steel couplers are used with diameter of 26 mm.

Drilling speed with these rigs in the platinum environment has been as fast as one minute per metre drilled - an improvement of some 20 per cent on a 32 mm hole and more on a larger hole. Drilling time, as well as the logistics with the smaller drill steel, will be much improved. Dedicated drilling and bolt installation systems will eliminate excessively large holes and offer support installation consistency.

The principles of the Autorock rig are:

- Rigid clamping of the rig between the hangingwall and foot wall
- Guided and powered thrust of the drill against the hangingwall increasing speed of drilling and reduced drill steel wear and breakages
- Remote operation i.e. the operator can be positioned safely under the already-supported hangingwall
- Modular lightweight construction, allowing easy maintenance and adaptability

Table II-Autorock drill rig sizes and weights

Rig size (mm)	Working height range (mm)		Rig weight (without drill) kg
	No extension legs	With extension legs	
650	670 – 1050	n.a.	20
750	800 – 1286	n.a.	24
950	950 – 1509	n.a.	30
1100	1100 – 1734	n.a.	34
1400	1400 – 2239	1450 – 3339	44
1600	1600 – 2439	1650 – 3539	50
1800	1800 – 2639	1890 – 3739	56
2400	2400 – 3239	2450 – 4339	75
3000	3100 – 3923	3100 – 5023	110

Figure 13-An Autorock in narrow stoping widths of some 0.9 m

Potential practical issues with polyester resin capsule bolting in hard-rock mines

Capsulated resin bolting is practised worldwide with great success. Successful resin bolting depends on the quality of the bolt, type of bolt, quality of resin, and correct speeds and sizes. Quality of installation requires correct hole sizes, spinning speeds, and holding before tensioning. Should these aspects be disregarded and the correct permutations be ignored, one will not have consistent, successful resin bolting. However, we need to acknowledge the following issues involved in successful resin bolting:

- Gloving or un-mixing - this occurs when the bolt, hole, and resin size are not optimum and the bolt spins inside the resin capsule resulting in a membrane layer between the hole sidewall and resin, which is not an ideal installation
- Over-spinning - when the operator continues to spin the bolt for longer than specified, which causes the resin to break, nullifying a bonded bolt installation
- Under-spinning - when the bolt has not been spun for long enough, resulting in slow setting of the resin
- Incorrect resin used in hot environments will result in premature setting, which prevents the bolt from being thrust to the end
- Spin-to-stall works but requires the correct resin for every application
- Correct hole sizes *versus* bolt size - the annulus i.e. the space between the bolt and the hole sidewall should be as small as possible to achieve best results. Two millimetres is excellent and larger than 4 mm may result in underperformance
- The best resin bolts are profiled to allow for improved mixing and improved pull-out force.

With good practice, resin bolt installations will offer the performance required.

Underground hard rock mines

FOG from the hangingwall still remain the larger contributor to rockfall accidents and injuries, and this paper addresses mainly this aspect of rockfalls, which will be discussed, with possible solutions, in the following sections.

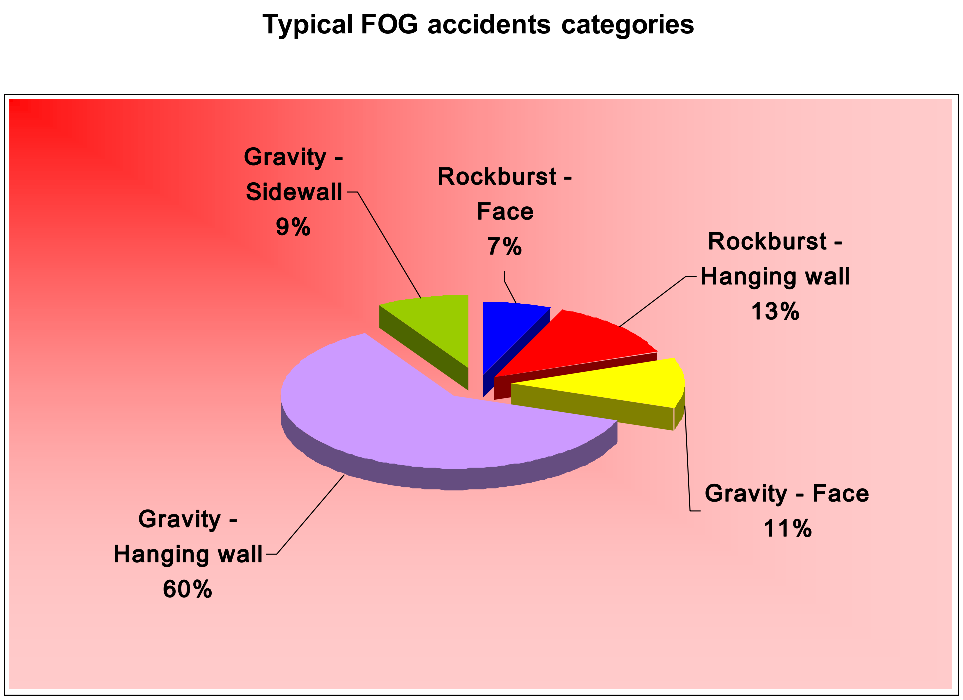

Figure 14–Typical FOG accidents categories

Support differences between coal mines and platinum mines

When attempting to adopt coal mining support technology, one needs to understand the differences between coal and platinum mining.

South African coal mining

- Highly mechanized
- High drill rotation speed and thrust available from mechanized machines
- Easy–to-drill 27 mm diameter holes and smaller (up to 22.5 mm) holes for optimum bolting
- Working height mostly > 1.8 m
- Temperature 18 – 20°C i.e. quite cool
- Rock density 1.4 – 2.5 t/m^3
- Systematic roof bolting is an established practice

Platinum mines

- Largely manual labour and non-mechanized with hand-held or similar drilling equipment
- Low drill rotation speed and thrust available from hand-held percussion rock drills
- Difficult to drill < 30 mm diameter holes with common sizes larger than 30 mm

- Blasthole sizes become support hole sizes, generally around 34 mm
- Working height mostly < 1.5 m for non-bord and pillar stopes
- Temperatures often > 28°C
- Rock density > 3 t/m^3
- Elongated and pack support established in-stope with some bolting

If bolting cannot be mechanized as in coal mining, then the technology must be adapted to suit the specific platinum mining requirements.

The need for change

Minova RSA decided to make the necessary changes to facilitate the adaptation of coal mining support technology on platinum mines, with the following and objectives:

- Adapt resin capsules to new demands i.e. two speeds in one capsule
- Create the appropriate ancillary systems i.e. resin insertion systems
- Simplify i.e. offer resin capsule as 'one' to fill any hole i.e. TOOSPEEDIE® double-clip capsule for full column
- Ensure that the process works every time i.e. change resin mastic to offer lower insertion force as required
- Spin-to-stall resin for warmer ambient temperatures and slower spinning to be developed
- Resin capsule characteristics and performance to match requirements of the industry
- Application methods to be best practice
- Customized bolts to suit the requirements
- Application equipment and the system is an integral part of the solution

Why two-speed resin capsule/spin-to-stall resin?

Spin-to-stall resin offers built-in best practice and was developed to offer:

- Assurance that the bolt has been correctly installed
- Long, two-speed capsule – one capsule fills the hole
  - No concerns about miscounts and under-filled holes
- Spin-to-stall means that operator timing is eliminated
  - Broken nut shear pin with 5 – 20mm thread shown in Figure 12 shows that the bolt took a 50 kN pre-load
- Faster bolting – fewer operator steps, no hold time waiting for resin to set
- Two speeds of resin in one capsule with fast resin a spin-to-stall

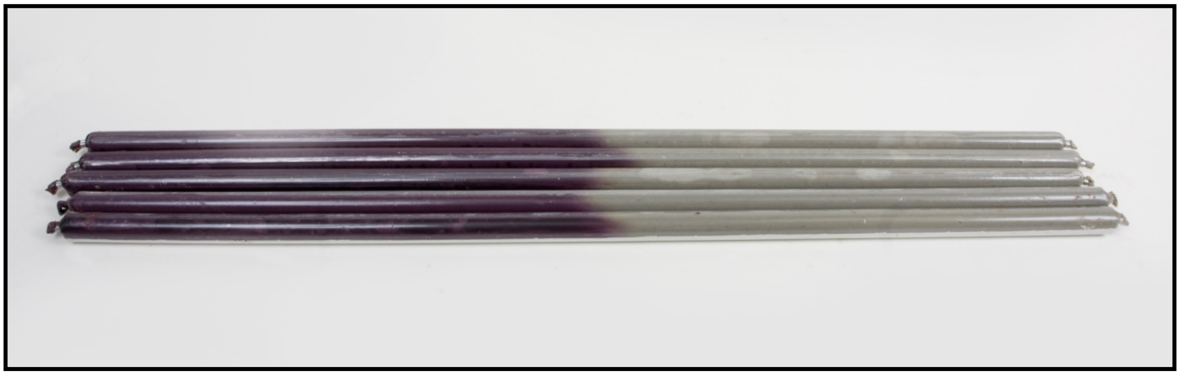

Figure 15-TOOSPEEDIE® capsules

Adapting the bolt to excessively large support holes

Steel rockbolts and resin capsules have long been used in South African mines as support. A constraint, however, has been the limitation of hole size compared to bolt diameter to ensure sufficient mixing of the resin and to overcome bolt in-hole performance with resin capsules.

Minova developed and patented the Secura Bolt™ to compensate for large support holes with smaller steel bolts. The Secura Bolt™ greatly reduces the risk of poor mixing of resin in-hole and improves the bolt pull out strength drastically.

The Secura Bolt™, which was first introduced in the Australian mining and tunnelling industry in 1997, is a specifically designed solid reinforcing steel bar for use in the strata support of underground mining and tunnelling excavations.

The Secura Bolt™ includes a unique paddle system to improve resin mixing and consequently provide higher bond strength in larger diameter boreholes. Secura paddles are formed using a unique shearing process, which results in a more consistent specification along the bolt length compared with traditional stamp paddle processes. Extensive installation testing has confirmed that the Secura paddle configuration assists resin film shredding and provides consistent and efficient mixing of resin capsule components. Furthermore, the Secura Bolt™ paddle configuration does not become caught on mesh during installation as with other resin mixing systems. This allows for easier installation of the bolt compared to a wiggle bar, and is superior in resistance and mixing.

Figure 16–Secura Bolt™ tips and cut open sections

Figure 17- Secura Bolt™ front end section of the bolt and installation

Figure 18-Secura Bolt™ distal end profile i.e. tip end and 300 mm tip end compared with straight bar.

Secura Bolts™ are supplied complete with shear pins, washers and load indicators to suit customer requirements. Numerous paddle configurations and paddle diameters are available to maximize performance in boreholes of various diameters. Secura Bolts™ are also available in various steel qualities, diameters, and lengths to suit individual strata support, excavation dimensions, and equipment requirements. All bolts can be supplied black or hot-dip galvanized. Secura Bolts™ have been successfully used as permanent support in mines and tunnels throughout Australia and New Zealand for over 10 years.

A full test programme to substantiate the improved performance offered by Secura Bolts™ specifically with 20 mm diameter steel bolts and smaller in large diameter holes drilled with 34 mm drill bits resulting in average hole size of 35 mm, and a test with slightly larger bolts was embarked upon. The objective of Secura Bolts™ is to improve resin mixing and resin bond strength for resin bolt installations in larger diameter holes. The tests were done on 250 mm standard SEPT, which does not reveal the full effect of the 300 mm Secura Bolt™. The results therefore are, in effect, understated. The South African tests are by no means absolute and conclusive, and further testing is taking place to establish the efficiency of the system. [“SEPT” is Short Encapsulated Pull Tests]

The results of the tests are summarized in Figure 19 and Table III.

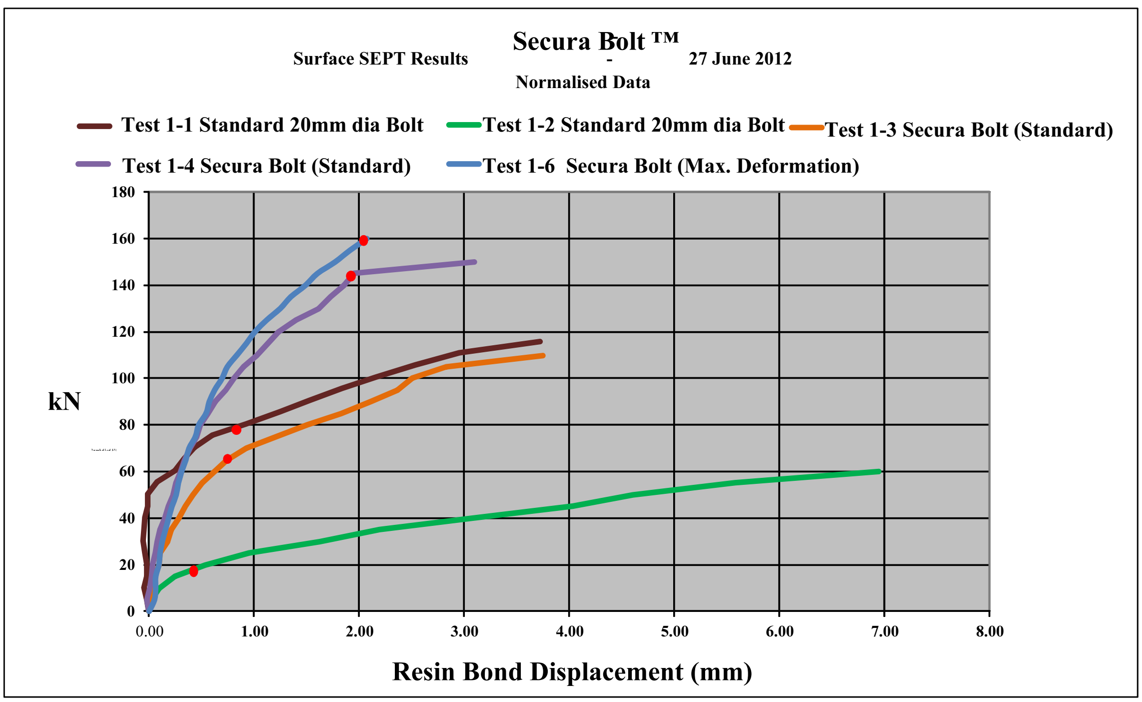

Figure 19-Initial results of Secura Bolt™ tests in granite block holes

Table III-Summarized bolt pull tests for straight and Secura bars

Secura Bolt ™

Bond Strength Performance For In-Situ SEPT — **Tests Conducted 05 July 2012**

Test No.	Test Purpose	Bolt dia (mm)	Resin Type	Bond lengt (mm)	Hole dia. (mm)	Resin dim. (mm) Dia	Resin dim. (mm) Length	Bond strength (kN)	Contact Shear Strength (kPa)	Comment
Test 2-1	Standard 20mm Ø Bolt	20.0	Minova 60 sec	264	35.3	32.0	218	60	2 164	Moderate bond strength, soft performance
Test 2-2	Standard 20mm Ø Bolt	20.0	Minova 60 sec	262	35.5	32.0	220	45	1 614	Very poor bond strength, soft performance
Test 2-3	Standard 20mm Ø Bolt	20.0	Minova 60 sec	262	35.5	32.0	220	1	36	Failed installation
Test 2-4	Standard 20mm Ø Bolt	20.0	Minova 60 sec	262	35.5	32.0	220	70	2 511	Moderate bond strength, soft performance
Test 2-5	Secura Bolt 18mm Ø (Std.)	18.0	Minova 60 sec	261	35.6	32.0	240	121	4 328	Excellent bond strength, stiff performance
Test 2-6	Secura Bolt 18mm Ø (Std.)	18.0	Minova 60 sec	262	35.5	32.0	240	98	3 515	Very Good bond strength, moderate stiffnes
Test 2-7	Secura Bolt 18mm Ø (Std.)	18.0	Minova 60 sec	261	35.6	32.0	240	54	1 931	Poor installation
Test 2-8	Secura Bolt 18mm Ø (Std.)	18.0	Minova 60 sec	261	35.6	32.0	240	79	2 825	Moderate bond strength,soft moderate stiffnes
Test 2-9	Secura Bolt 20mm Ø (Std.)	20.0	Minova 60 sec	257	35.9	32.0	223	105	3 724	Very good bond strength, stiff performance
Test 2-10	Secura Bolt 20mm Ø (Std.)	20.0	Minova 60 sec	261	36.0	32.0	228	5	177	Failed installation
Test 2-11	Secura Bolt 20mm Ø (Std.)	20.0	Minova 60 sec	261	36.1	32.0	230	118	4 162	Excellent bond strength, stiff performance
Test 2-12	Secura Bolt 20mm Ø (Std.)	20.0	Minova 60 sec	262	35.4	32.0	218	141	5 071	Excellent bond strength, stiff performance
Test 2-13	Secura Bolt 20mm Ø (Max)	20.0	Minova 60 sec	262	35.9	32.0	227	107	3 795	Very Good bond strength, moderate stiffnes
Test 2-14	Secura Bolt 20mm Ø (Max)	20.0	Minova 60 sec	259	35.8	32.0	223	160	5 690	Excellent bond strength, stiff performance
Test 2-15	Secura Bolt 20mm Ø (Max)	20.0	Minova 60 sec	261	35.6	32.0	221	160	5 722	Excellent bond strength, rather stiff performance
Test 2-16	Secura Bolt 20mm Ø (Max)	20.0	Minova 60 sec	262	35.7	32.0	224	160	5 706	Excellent bond strength, stiff performance

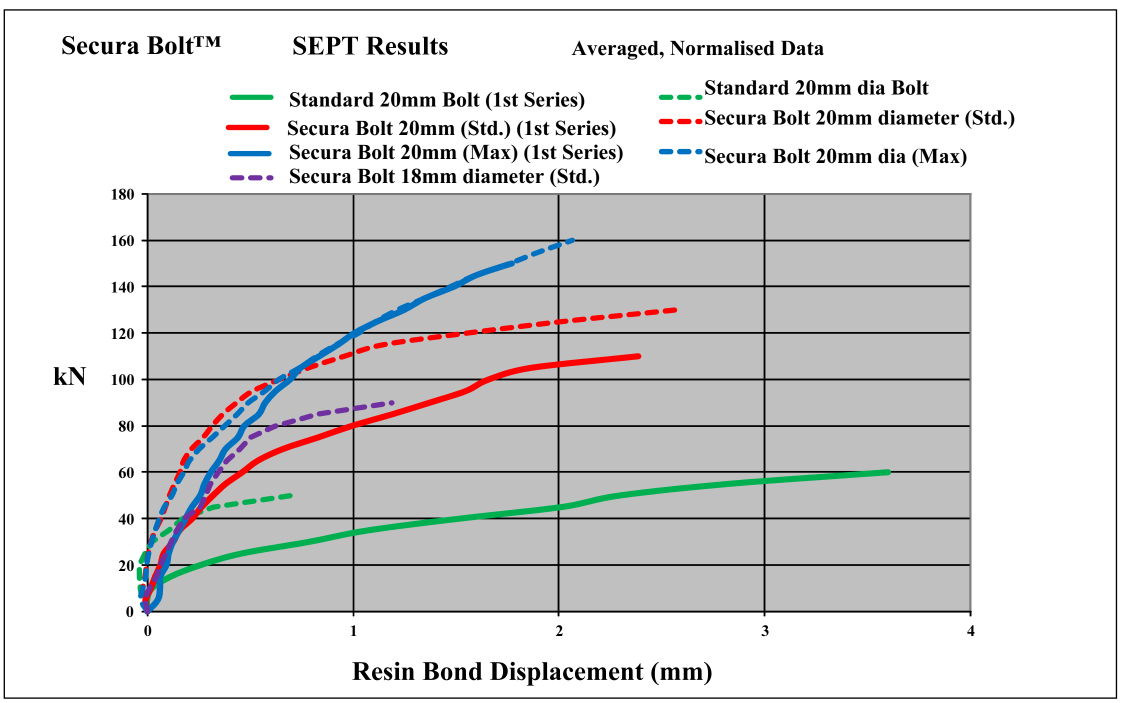

Figure 20-Summary of the date in Table III clearly showing improved Secura performance and meeting the 1 mm specification for displacement

The test results for 5 July 2012 are shown in Table III and graphically represented in Figure 20. Figure 20 indicates a clear distinction between the different groups of rockbolts tested. The graph can be divided into four areas as defined by the different bolts. The Secura-Bolt™ (Max) 20 mm diameter again outperforms all the other bolts and tested very similarly to the initial tests. This bolt offers a very stiff performance, not allowing much displacement and results in high bond strength with approximately 1 mm resin bond displacement for 120kN of applied force.

The standard 20 mm diameter Secura-Bolt™ is the next best performer and offers a very stiff performance resulting in high bond strength with approximately 1 mm resin bond displacement for 100 kN of applied force. It also performs slightly better than the 18 mm diameter Secura-Bolt™, with approximately 1 mm resin bond displacement for 90 kN of applied force.

The significance of this is the benchmark of less than 1 mm resin bond displacement for 100 kN of applied force. The 18 mm Secura-Bolt™ typically tests below this standard, but the same results are still significantly better than the standard 20 mm rock bolt. The standard 20 mm diameter rock bolt in this environment typically results in 1 mm resin bond displacement for 40-50 kN of applied force.

The results clearly show a marked improvement in pull strength with a Secura Bolt™ in large holes compared with a straight bolt. This implies that a Secura profile enhances a resin bolt installation and should be used in almost every installation.

Aspects and advantages to consider include:

- Proven historical performance in Australia and now South Africa
- Extensive quality-controlled manufacture
- Permanent single pass bolting
- Can be used as a coupling bolt as well
- Multiple lengths, diameters, paddle configurations
- Consistent pin nut torque drive system
- High-strength thread
- Proven resin mixing performance
- Full encapsulation maintained
- Available in black or hot-dipped galvanized steel
- Can be used in the most common resin bolt hole sizes
- Uses same installation procedures as regular resin bolting
- Cost-effective use of existing manufactured products
- Increased bond compared with straight bars

- Superior resin capsule in-hole mixing
- Used on standard or special steel bolts ranging from 16 mm to 25 mm
- Offers at least 50 per cent improvement in pull strength compared to a straight 20 mm bar in same large hole size for a 18mm Secura bar. For a 20 mm Secura bar STD the bond strength even doubled. It is evident that the Secura profile adds tremendous value to bond strength. In much smaller holes the percentage difference will be smaller.
- Requires increased thrust to insert the bolt into the resin-filled hole

To further support these tests, extensive evaluation of Secura Bolts™ was completed in 2008 at Minova's full-scale bolt simulation facility in Nowra, NSW Australia. The primary objective was to determine the best possible bolt, paddle, and borehole diameter combinations to ensure consistent resin mixing during *in-situ* installations.

Appropriate application equipment for effective support installation in-stope

The use of mini drill rigs for drilling stope bolting holes offers:

- Essential rigid clamping of the drill rig especially for small hole drilling and small drill steels
- Directed thrust of drill steel and bolt
- Better resin mixing and faster bolt insertionRemote control operation, ensuring operator safety

Figure 21-Remote drilling and installation of rock bolts

The value of in-stope bolting

In-stope bolting has proven to be an effective means of support in a number of platinum mines. What value does in-stope bolting add to the operations?

- Bolts can be installed right up to the face, offering active support
  - Major reduction of the unsupported span
  - Most critical work area has permanent support
  - Clamping of key blocks in place
  - Helps facilitate the installation of nets.
  - Bolts leave stope open for mechanized equipment – face drill rigs, loaders, etc
- Bolts can provide immediate secure face conditions, as most bolting offers stiff support
  - Stabilizes the hanging wall and pins fractures in order to reduce FOG

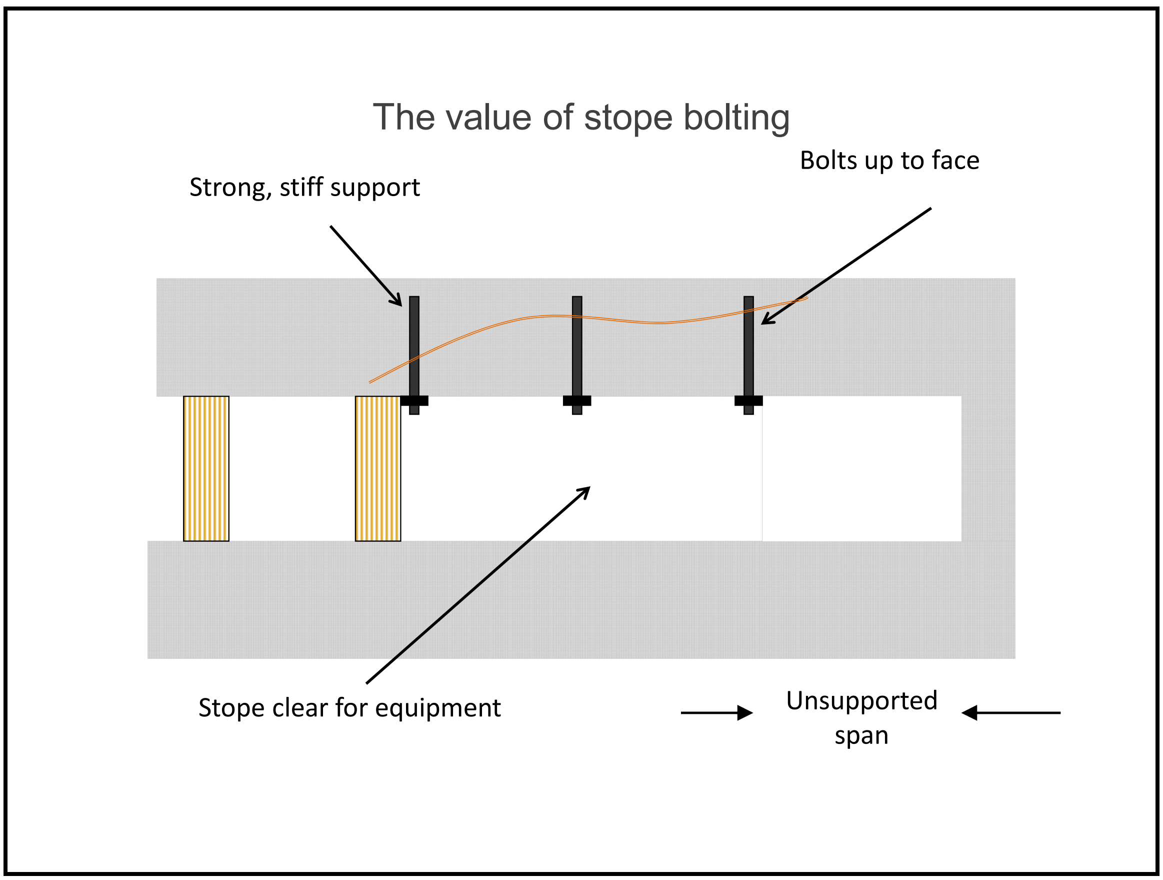

Figure 22-Typical narrow stope panel with bolts on the face

To achieve these benefits one needs:-

- Safe, reliable, efficient drilling of support holes and installation of appropriate bolts. Small hole drilling (25 mm to 28 mm diameter at maximum in hard rock for resin bolts is preferred along with 20 mm steel bolts)
- Fast-acting support and active support combined with an appropriate semi-mechanized small drill rig to drill and install a resin bolt, leaving a completed bolt installed before rig removal
- Reliable system that works every time with a sure method of installation that safeguards management; good bonding of the bolt with the rock addresses friable ground
- Generally a strong and stiff bolting system

Figure 23-Rock bolts and pre-stressed mine poles installed in the gully for competent support

Resin bolt compared to an inflatable friction bolt - risk management issues

Inflatable friction bolts are commonly used in platinum mines as in-stope support. Below are some points to compare inflatable friction bolting with resin bolting.

With resin bolting:

- Broken shear pin shows bolt is properly installed
- Load indicator is proof of torque applied
- Use of a single resin capsule ensures full column and offers management control

- Two-speed resin gives active support with an end-anchored resin bolt
- Spin-to-stall improves speed of installation and offers management control
- Resin protects bolt from corrosion and acts as a permanent support
- Small holes required for effective resin bolting with standard bolts
- Built-in installation discipline offers management control
- Offers much higher loads and is a stiff support

With inflatable friction bolting:

- Coloured pin in nozzle indicates proper filling and offers management control
- Considered a short-term support system
- Not good in friable ground as the bolt does not bond with the rock
- Large holes required
- Bolts can be installed long after holes have been drilled, increasing the risk of FOG.

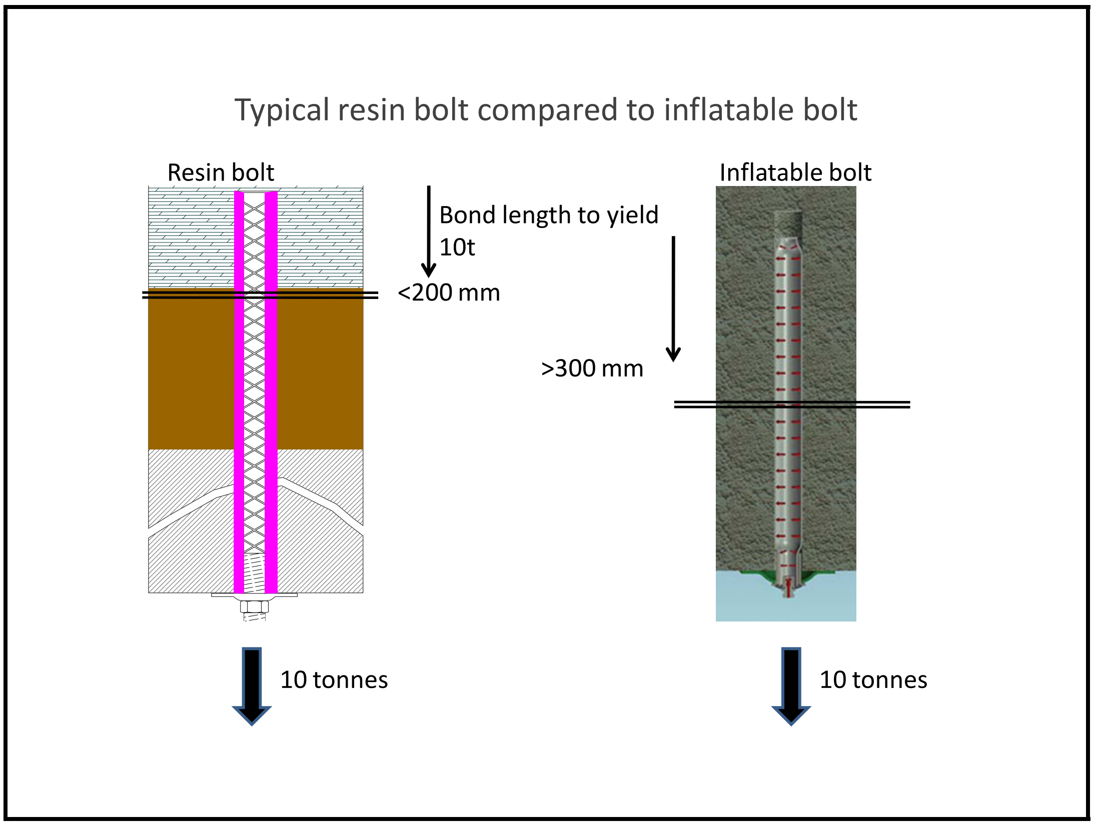

Figure 24-Resin bolting compared to inflatable friction bolting

In-Stope Autorock and resin capsule bolting system

It is widely recognized that resin-grouted rockbolts provide the strongest form of rock support, coupled with immediate support action and long-term durability. Where conditions permit, it is advisable to use resin capsules and steel bolts for in-stope and development end bolting.

Some additional aspects to be considered with clamped rig installed resin bolts are:

- The drilling of the support hole and the complete installation of a steel rockbolt with resin capsules offers a cost-effective, safe, simple, and fast support solution
- Increased speed of drilling small holes and installation of smaller bolts
- Resin bolting with an Autorock ensures support installation discipline – *viz*. the rig is not moved away from the installation until the installation is 100 per cent complete (no pre-drilling and post-installation of bolts)
- Two-speed resin capsules provide almost perfect full-column grouting along with the correct hole size, appropriate bolt and washer, shear pin, and load indicator
- Immediate high-quality support, once bolt is tensioned with the rock drill
- Steel bolt shear pin and load indicator provide visual proof of a successful installation, giving management peace of mind and control
- The drill steel changes with an Autorock are fastest compared to other units in the field and offers most daylight above the rock drill.

Small hole drilling in hard rock

Small support hole drilling in hard rock requires quite a serious change in mindset. To this end, a complete system to accomplish this is available. Small hole drill using 25 mm bits and 19 mm drill steel is aimed at small rig drilling only and not straight hand-held drilling.

The system incorporates the following:

- Drilling of 25 mm diameter holes where bolt length required is less than the stoping width
- Drilling of 28 mm diameter holes for use with coupled bolts or cable anchors where anchors longer than the stoping width are required
- Use of 19 mm hexagonal drill steel, with 25 mm or 28 mm and appropriate bits
- Hand-held rock drills specific for and dedicated to rockbolting, fitted with 19 mm chuck bushes, along with 19 mm drill steel as a complete solution equipped in a drill rig for perpendicular thrust and drilling
- High or higher tensile support steel than the standard 500 MPa 20 mm steel bolt
- Slim-hole bolts and cable anchors for customzed solutions
- Large enough thrust and spinning equipment is required with longer holes used with Secura Bolts™

Figure 25. - Spinning and torque unit fitted to a standard pneumatic drill for long hole resin bolting

Aspects to consider:

- Smaller holes with correct bolts give improved resin bolting performance
- Faster drilling from smaller diameter holes
- Lower cost of bolts and resin as a unit
- No risk of oversized rock bolt holes, as the blast hole drilling components cannot be confused with the rockbolting components
- A dedicated support system, reducing and minimizing substandard practice

Quick-Chem™ resin capsule insertion system

Quick-Chem™ is a patented system developed to install resin capsules remotely into boreholes for rockbolting. The Quick-Chem™ system has been developed to mechanically install resin capsules where hand installation is not safe or practical. Quick-Chem™ consists of purpose-designed retaining caps, which are attached to resin capsules and insertion tubes. The tubes are fitted into the drifter of development jumbos. Caps are fitted to the resin capsules and inserted into the tubes. The jumbo boom is then used to insert the tube and resin capsules undamaged to the back of the hole.

Figure 26-Quick-Chem™ tubes and chuck connectors as well as resin capsule caps in tubes

This is a resin capsule insertion system for development jumbos that is commonly used in Australia and is beginning to be used in South Africa where dedicated bolters are not applied. The resin is installed in seconds with no permanent attachments.

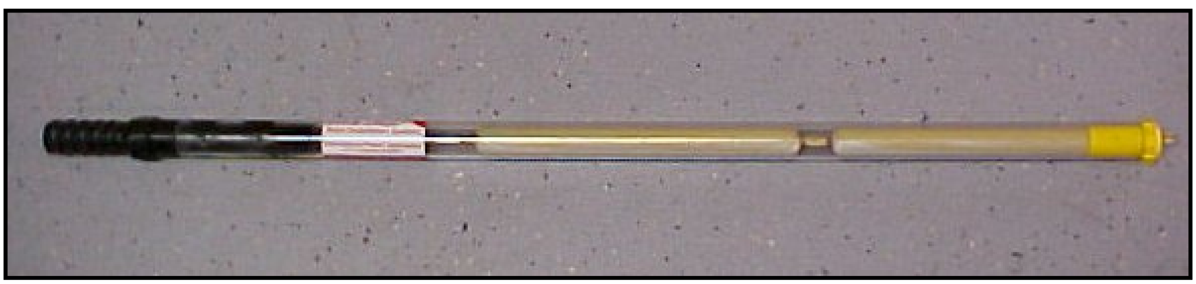

Figure 27-Quick-Chem™ tube loaded with resin ready for insertion in to chuck and hole

Specially designed retainer caps are available in different sizes for different hole sizes and resin capsule diameters. When the tube is inserted to the back of the hole, where the resin is suspended, the cap ensures that the resin is held in place at the back of the hole once the tube is withdrawn. This avoids manual loading with a loading tube under an unsupported and unsafe hangingwall.

Figure 28-Jumbo loaded with Quick-Chem™ tube inserting tube with resin into the hole

Figure 29-A special face jumbo used to load the resin and insert bolts, making a complete installation

Where to from here?

Appropriate support systems are available to make a significant contribution to safety in our mines today. By making use of suitable and better support systems, Section 54 stoppages could be greatly reduced, with fewer falls of ground and fewer violations of mine standards with improved system usage.

The initial costs incurred in the application of the improved support systems will be offset by the reduced losses due to Section 54 stoppages, to say nothing of reduced injuries and fatalities.

The industry should:

- Strive to apply and use the best support systems available today as widely as possible

- Transfer support technology from the coal sector to platinum

- Adopt resin rockbolting so that it can become as effective and widespread as in coal.

Resin bolting in platinum stopes is a practical proposition.

Mesh, whether it is steel, GRP, or other material, should be the chosen area support in stope hangingwall, gullies, and development ends.

Conclusion

The industry should consider:

- Introducing in-stope bolting as far as possible along with other relevant support
- Using in-stope drill rigs in conventional narrow-vein stopes to drill and install support
- Using a double-clamp drill rig with resin bolting to provide built-in discipline and as fail-safe a system as possible
- Using the Quick-Chem™ resin bolting system with mechanized or even conventional systems
- Implementing the use of mesh as additional cover against FOG in all working places
- Introducing spin-to-stall resin bolting in development ends and stoping

- Introducing two-speed resin capsules with resin bolting converting support drilling and hole size to support safe practice requirements and not mix with blast hole requirements. Dedicating and paying attention to support installation systems without compromise
- Introducing TSLs for improved rock surface coverage reducing FOG

Best practice, proven technology, and best support systems can and should be implemented.

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