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Integrated solutions based on injectable bulk resin for fast and safe rockbolting

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Abstract

Integrated rockbolting means a coordinated R&D strategy aimed to optimise all elements involved in the process. The paper focused on fully grouted rockbolts where urea-silicate resin (USR) is the bonding medium between steel and surrounding rock. USR is delivered and stocked in large containers and can be injected into the hole by pumps via a static mixer. This paper analyses pre- and post-grout techniques used to inject USR in the hole and how these two systems can be applied to the two major rockbolting procedures, i.e. with mechanised bolting rigs or face drilling jumbos. USR can be used with different types of rockbolts, namely self-drilling bolts, hollow bar bolts, solid rebar bolts and cable bolts. This paper discusses the advantages of using USR in all these applications, presenting results obtained in laboratory tests and field cases. In general, USR represents an opportunity to improve quality and quality control of rockbolting and therefore mine safety and offers the opportunity to reach better bolting productivity which is a smart way to decrease total operational cost in underground rock excavation.

Keywords: *mechanised rockbolting, urea-silicate resin, injectable bulk resin, jumbo bolting, pre-grouting, post-grouting, total cost of operation*

1 System integration: a modern approach to injectable resin-grouted rockbolting

1.1 How to reach fast and safe resin-grouted bolting systems

Cement or resin-grouted bolts are often the preferred rockbolting solution due to higher loading capacity, longer service life and higher reliability in case of poor rock. But mining industry has requested faster and more reliable bolting systems, easier to be integrated in current and future excavation processes, more mechanised and less dependent by operators' skills and less influenced by logistic hurdles (Osinga 2018).

Sandvik Underground Drilling and Ground Support divisions have joined R&D resources with a clear mission to integrate drilling rigs, a urea-silicate resin (USR) dispensing system (pumps, mixers, nozzles, etc.) and load-bearing elements (rebar, hollow bar bolts or cable bolts) into a comprehensive program. The main targets for this integrated system are illustrated in Table 1.

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Table 1 Potential practical problems occurring during installation of grouted rockbolts and targets for urea-silicate resin integrated bolting strategy

Target	Current problem with bolt installation	USR integrated bolting strategy
Increased quality control	Potential partial encapsulation, poor mixing, or gloving effect	Pre-dose, pre-mixed resins in correct quantity fit to borehole volume
Increased safety	Poor control over installation sequence and parameters	Total QC/QA of all major installation parameters
Improved productivity	Capsule misfiring, lost boreholes	Simple and repeatable installation cycle
Improved productivity	Material not always available	Large resin tanks mounted onboard
Total cost of operation	Rehabilitation works, lost ore	Reliable loading capacity even in broken ground + more bolts/shift → faster excavation and less ground instability
Total cost of operation	Slow cable bolting and long re-entry time (in case of cement grout)	Fast curing, easy-to-install resin for immediate ground support and rapid re-entry

1.2 System versatility: extend urea-silicate resin to several bolting methods

Ground support strategy in general and rockbolting installation methods in particular differ in different part of the world (Schunnesson et al. 2019). In Australia rockbolting by twin boom face drilling jumbos is largely preferred. In Europe and North America fully mechanised bolting rigs are common. In Canada semi-mechanised bolting (drill unit on a service platform) is popular.

When skilled operators are available, jumbo bolting is highly productive, especially when installing friction or hybrid bolts (such as MD or MDX). Thanks to long resin capsules, packed in a plastic tube or pneumatic ‘shot-guns’, grouted bolt installation is a common practice too; however more complex installation sequence causes lower productivity. A study comparing bolting procedures utilised in eight underground mines (Gustafsson et al. 2016) suggests that rockbolting systems with good repeatability of installation cycles, high rig utilisation and less logistic hurdles provide better productivity

Fully mechanised cable bolters allow a safe and productive installation of long cement-grouted reinforcement elements. However, re-entry to the bolted area is restricted by the curing time of the cement grout normally used in this application.

Bulk, injectable USR resin made available has been introduced in association with mechanised bolting rigs (Bray et al. 2019) reaching interesting results (Bergman et al. 2023).

The project described in this paper wanted to extend the use of USR to other bolting procedures, namely jumbo bolting and cable bolting.

1.3 Versatility needs: type of rockbolt

USR has been introduced in association with self-drilling bolts (SDB) and hollow bar bolts (HBB) (Bray et al. 2019). Not all mining operators are prepared to replace traditional rebar bolts with (more expensive) hollow bars. Similarly the replacement of cable bolts with SDB has not been widely accepted.

The objective of this project is to study the possibility to extend application of USR to more ‘standard’ reinforcing elements such as rebar bolts and cable bolts.

2 The opportunities given by bulk injectable USR

Styrene-based polyester resin has been used for decades as bonding agent for rockbolts, commonly delivered pre-packaged in capsules. Polyester resin contains a large quantity of filler (generally limestone in grains) which allows the admixture to reach high compressive and shear strength. At the same time, fillers increase viscosity and the need for vigorous mechanical actions to mix polyester mastic peroxide catalyst. There are promising efforts using styrene-based polyester mastics and bulk injectable systems (Robert & Faulkner 2019), but these struggle with the unavoidable challenges posed by their high viscosity which requires heavy and large high-pressure pumps. The presence of styrene is a EHS concern too.

In recent years, several players have developed bonding media based on USR. This system is based on PMDI (**p**olymeric **m**ethylene **d**iphenyl di**i**socyanate, which is commonly used in mining and civil industry) and waterglass. It does not contain any filler, and has the following benefits:

- Easy pumpability and components handling. Very high component`s durability (> two years shelf life, no separation).
- High-temperature stability of the components. Components are resistant to freeze-thaw cycles and elevated temperatures.
- Being free from highly flammable components (such as styrene), it can be handled safely by bulk packaging, which significantly improves mine logistics and tank refiling.
- No interoperation mixing is required and components can be processed using commonly accepted/available light pumping equipment.
- The USR systems presented in this paper are fully hermetic, do not pollute the working environment and do not impact workers.

Thanks to these logistic and operational advantages, USR bonding solutions have gained wide interest in mining ground support, with mechanised boilting rigs operating using USR as a grouting agent with SDB (Bray et al. 2019) and HBBs (Bergman et al. 2023).

2.1 Is urea-silicate resin bulk injectable resin strong ‘enough’ for rockbolting?

The compressive strength of the standard polyester and USR resins is 40–60 MPa, however, USR is a more ductile material with the ability to yield. As a result material failure (ultimate compressive strength) is observed at much higher deformations around 30% instead of 3% which is typical for polyester resins.

Back in 2021, the authors received the request to prove that a R25 Ductile HBB grouted with USR could replace a ‘traditional’ polyester grouted 20 mm, B500 grade steel rebar bolt. In order to give qualified answer the Norwegian University of Science and Technology (NTNU) were tasked with comparing the two options using their well-known tensile and shear testing facilities. Figure 1 illustrates the rig utilised and the diagrams obtained.

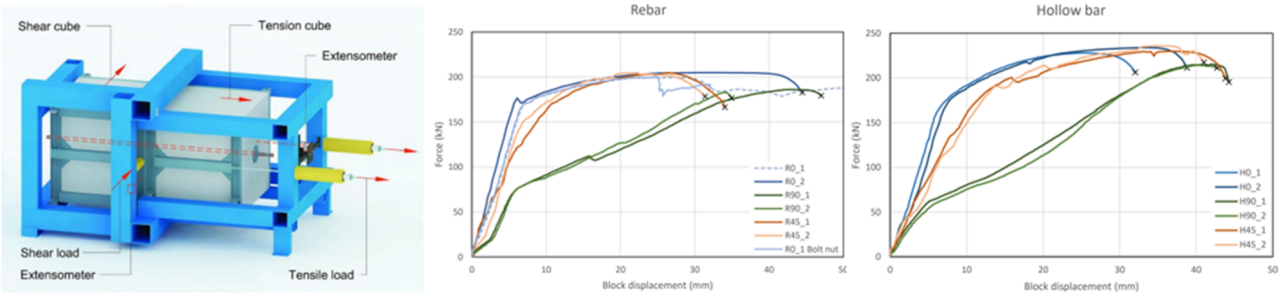

Figure 1 NTNU tensile and shear test, showing the comparison between a DSI 20 mm rebar bolt grouted with polyester FASLOC resin and a DSI R25 ductile hollow bar bolt grouted with mineral bolt urea-silicate resin

The tests gave positive results about USR-HBB bonding strength and in general the performance of the system. Bond strength is a physical dimension more appropriate than compressive strength, since it takes into consideration the interaction between steel and the bonding agent.

Filler-free USR resins are strong enough and stable enough to replace polyester resin, at least in certain well- identified conditions and with well-identified association of products (steel a resin).

In general, it is highly recommended to measure in-situ bond strength between steel and resins and resin-surrounding rock.

2.2 Integrated urea-silicate resin bulk injectable resin: productivity and quality control

The greatest advantage of USR pumpable systems is the fully automated and controlled resin processing, including:

- simplified operational sequence
- resin dosing to borehole (volume)
- resin mixing (flow, pressure)
- component pumping parameters (flow, pressure)
- tracking of the available resin volume in the tanks.

Full control of the resin process provides high repeatability and improves process QA/QC with direct impact on safety and total cost of operation. The resin injection is typically controlled by maximum resin intake per hole, which is a typically used as a stop criterion of the process. Figure 2 illustrates how borehole geometry (radial and longitudinal position, drilled length) is integrated with resin pumping parameters.

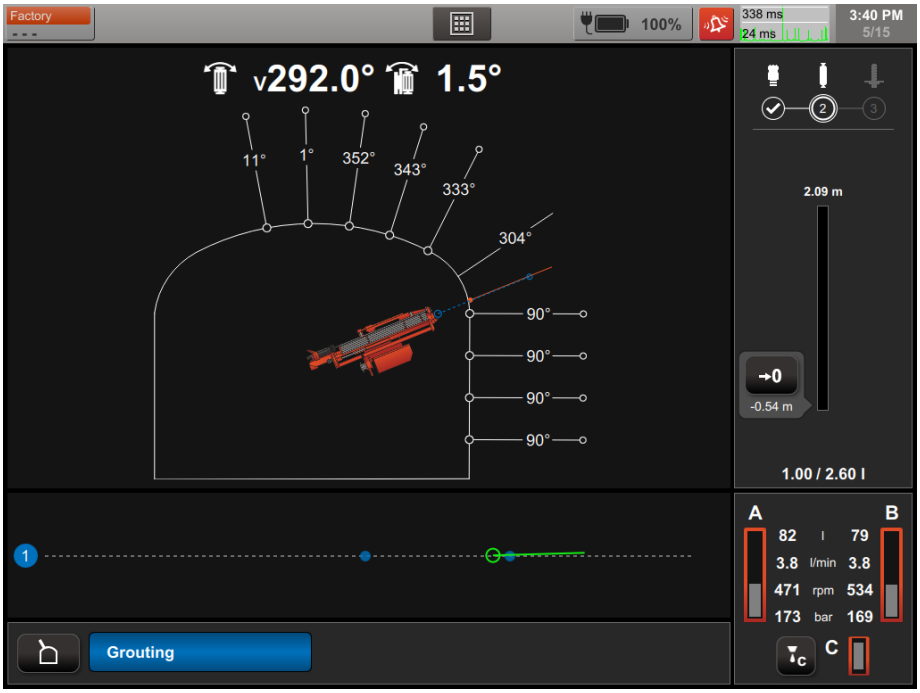

Figure 2 Figures showing operation panel. Clear view on drilled hole geometry. (A), (B) Resin volume in the tanks; (C) Pumped resin parameter (volume and temperature)

- Enhanced automation:
  - Enhanced automation allows reduction of the installation cycle times and (even more important) repeatability and reproducibility of the cycle. The combination of the two is expected to increase long-term productivity and therefore reduce total cost of operation.
  - The whole installation process and installation steps are automated, so after the procedure launch the cycle cannot be interrupted. There is very limited operator involvement or none at all, and human intervention can be concentrated to problem solving such as fine-tune collaring or unexpected blockages. A control system observes the injection process at all times and if an error occurs, it stops the process and informs the operators. Bolting cycle time can be easily tuned and reduced to the necessary minimum.
- Enhanced digitalisation/connectivity:
  - Bolting systems based on USR bulk resin injection system can be easily integrated in advanced digital platforms made available on most modern 'intelligent' drilling and bolting rigs, as presented in Figure 3. Each step of the installation process will be captured and analysed afterward.

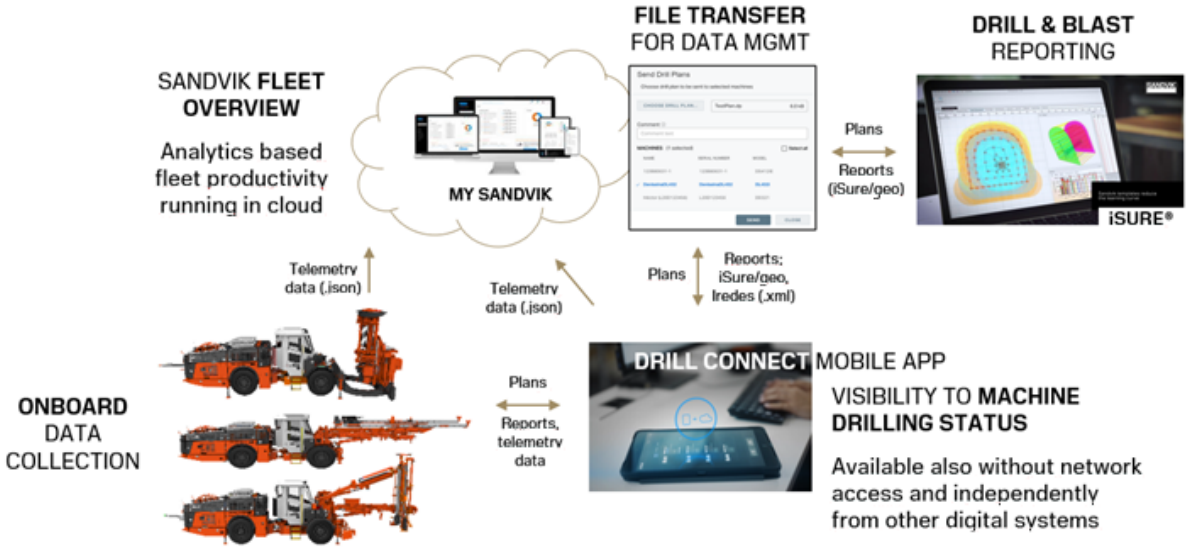

Figure 3 Injection process parameters are going to be part of Sandvik iSure/geoSure digital platform, a solution 'iSeries' rigs intended to collect, record and manage data for geotechnical purposes, together with visualisation capabilities

2.3 Integrated bulk injectable urea-silicate resin: safety aspects

An automated (without operator involvement) continuous resin mixing and grouting process guarantees that the resin has continuous homogeneity, resulting in high resin performance regardless of the bolt length. This phenomenon significantly improves the quality and therefore safety of anchor installation.

Moreover, continuous and uniform resin parameters improve load transfer and corrosion resistance. Human errors (such as incorrect water:cement ratio, not fully grouted holes for cementitious grouts, process-related issues commonly known for resin capsules as film shredding, or broken capsules before entering into borehole) are eliminated.

Finally, pumpable resin systems are not sensitive to annular gap and can be used even in the case of big differences in borehole/anchor geometry. For instance, 51 mm borehole and 22 mm rebar or 15.2 mm cable (although the increased annulus has an impact on the shear strength capacity of the bolt).

R25 and R28 SDB can be installed in holes drilled by 45–35 mm bit.

Another important feature of the bulk injectable resin is application versatility, allowing for quick modification of the quantity of resin injected, adapting it to changing ground conditions. In case of good rock conditions, bulk resin is dispensed in the minimum quantity to get full rockbolt encapsulation. Safety improvements become relevant in case of weak and/or fractured rock, where a larger amount of bulk resin can be injected to fill any larger-than-expected borehole volume and fill open cracks, with positive consolidation effects.

Finally, injectable resins can be also used for extension drilling by SDB. For instance, a solution based on two sections of 3 m-long SDB can be used as an alternative for short cable bolting in the intersections. These bolts can be installed by same mechanised bolting rig used for shorter bolts, with advantages in logistic and machinery fleet utilisation.

3 The versatility of integrated bulk injectable urea-silicate resin

USR bulk injectable resins can be used in association with a large variety of rockbolts:

- HBB/SDB are available in different sizes, in standard or ductile steel and even partially de-bonded ("dynamic" version). Generally hollow bars are associated with post-grout installation method
- Solid rebar bolts of different sized and characteristics and cable bolts are preferably installed with pre-grout method.

Table 2 associates rockbolt types to the installation method, i.e. semi-mechanised procedures (typically a jumbo) or fully mechanised procedures (typically a bolting rig), obtaining five main cases.

Table 2 Rockbolt types and application methods

Integrated bulk injectable urea-silicate resin				
Solid rebar	Hollow bar bolts (HBB)/self-drilling bolts (SDB)	Cable bolt	Solid rebar	HBB/SDB
Pre-grout	Post-grout	Pre-grout	Pre-grout	Post-grout
Mechanised bolting rig	Mechanised bolting rig	Mechanised bolting rig	Face drilling jumbo	Face drilling jumbo

Modern resin injection systems are fully integrated for each application for highest installation quality for each bolt. Computer-controlled drill rigs may record, store and transmit all data for each step in the bolting process sequence, toward a total QA/QC approach to ground support.

3.1 Post-grout dispensing systems

Post-grout dispensing systems are used with hollow core bars like HBB, SDB, hollow cable cables, or solid bars equipped with grouting hose. The resin is mixed on the inlet to the borehole and is delivered to the hole bottom via the hollow core of the bolt. Installation sequence is presented in Figure 4.

1. Borehole drilling with SDB.
2. The drilling is stopped when it reaches the desired borehole length.
3. The resin flow is activated, and the borehole is continuously filled top-down.
4. Grouting is continued until the desired resin volume is achieved or resin is observed at the collar.
5. The nut is tightened.

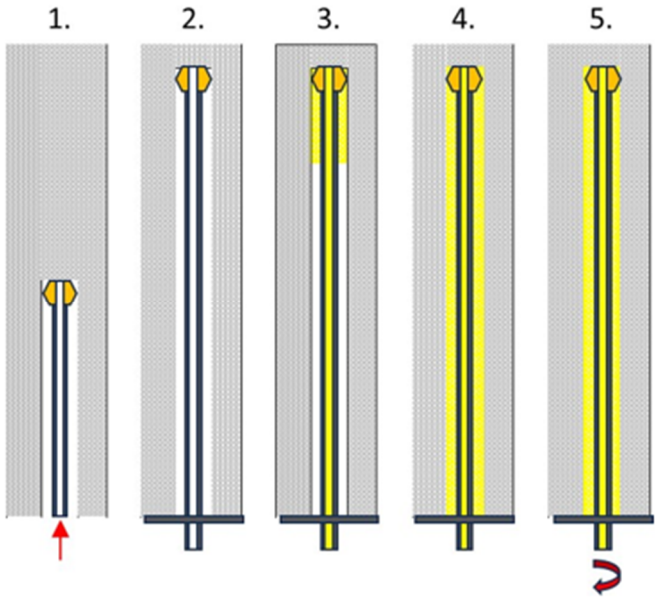

Figure 4 Installation steps of the post-grout dispensing system, in this case self-drilling bolts (SDB)

The advantages and disadvantages of post-grout dispersing systems are presented in Table 3.

Table 3 Advantages post-grout dispersing systems, i.e. first inserting the (hollow) bolt in the hole and then inject urea-silicate resin from the hollow centre of the bolt

Advantages	Disadvantages
Correct resin quantity for full encapsulation	Only bolts with hollow centre (self-drilling bolts [SDB]/hollow bolt bar [HBB])
Very easy and simple installation	Higher cost of the bolts, larger volume of resin
Holes drilled with drilling rod (only for HBB)	Holes drilled with sacrificial drill bits (only SDB)
No sensitivity for annular gap	Only SDB
Extension drilling is possible	–

3.2 Pre-grout dispensing systems

Pre-grout dispensing systems are used with solid anchors such as solid bar, rebar, or cables. The resin is mixed on the end of the grouting lance (see Figure 5).

(a) (b)

Figure 5 Typical manual grouting lance. (a) Delivery tubes; (b) Static mixer

Pre-grout dispensing systems can be recommended for good rock condition with no collapsing boreholes, rebar lengths up to 3 m or cable bolt lengths up to 6 m. The critical step in this application is anchor insertion immediately after borehole filling. Installation sequence is presented in Figure 6

1. Inserting the grouting lance into the borehole.
2. The lance is stopped when it reaches the end position.
3. The resin flow is activated, and the borehole is continuously filled while the injection lace is withdrawn.
4. Grouting is continued till the desired resin volume is achieved.
5. The anchor is inserted into the grouted borehole.

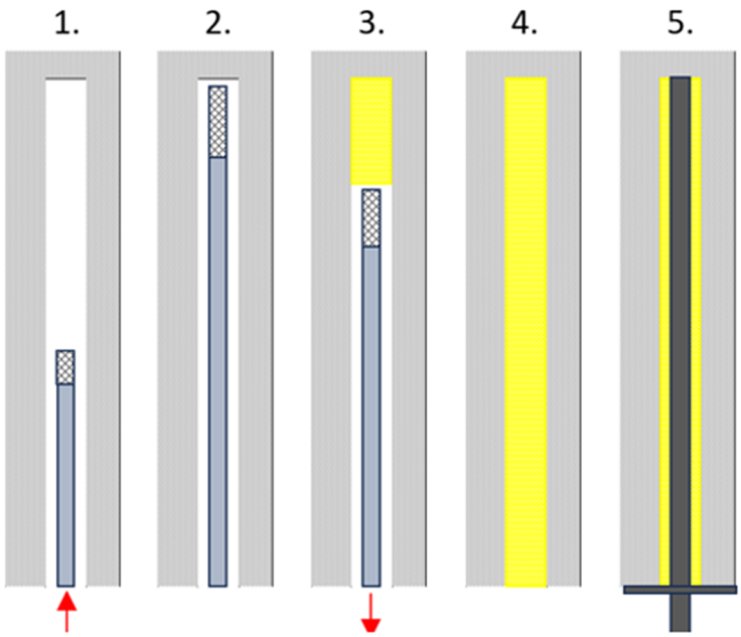

Figure 6 Installation steps of the pre-grout dispensing system

The main advantages and disadvantages of pre-grout dispersing systems are presented in Table 4.

Table 4 Advantages and disadvantages of pre-grout dispersing systems, i.e. first filling the hole with urea-silicate resin and then insert the bolt

Advantages	Disadvantages
Standard ordinary bolts can be used Resin volume depend on borehole geometry	Resin volume limited by borehole volume
Easy and simple installation	Hole length is limited by the grouting lance length
Holes drilled with drilling rod	Resin reaction time must be precisely tuned
No sensitivity for annular gap	Extension drilling is not possible

4 Brief guide to integrated urea-silicate resin bolting solutions

4.1 Hollow bolt bar installed by mechanised bolting rig

Hollow bar installation is a complete automated process on rock bolters. The installation process has three different phases:

1. drilling
2. hollow bar insertion
3. post-grout.

Being a fully bonded bolt, HBB has not any free-length and cannot be ‘tensioned’. If required, the nut can be tightened so the face plate and wire mesh can adhere well to the rock surface. If feed pressure is high enough to push the rockbolt plate against the rock, the installation cycle gets shorter with an increase in productivity.

Hollow bars and USR have been successfully adapted for mechanised installation in hard rock mines (Bergman et al. 2023). The advantages are summarised in Table 5.

Table 5 Advantages hollow bar bolt (HBB) installation process by a mechanised bolting rig

HBB and urea-silicate resin and mechanised bolting rig: advantages
Maximum productivity with mechanised bolting rigs, emulating what achieved with friction bolts Fast and reliable drilling even in hard rock, no extra costs for disposable drill bits
Full encapsulation regardless annular gap, broken ground, open cracks
Great selection of hollow bar dimensions in standard, ductile and dynamic versions

The use of 'mineral bolt super-fast' USR with reaction times of 20 s shortens HBB cycle time to the minimum. A fully mechanised bolting rig can reach a shift production in the range of 100 bolts, i.e. comparable to the same rig equipped to friction (no grout) bolts.

HBB do not permit a mechanised installation of long, coupled rockbolts. Certainly HBB steel and associated resin cost more than standard solution based on solid bars. The authors suggest considering the total cost of ground support per metre of excavation; not always, but often, higher productivity and better geotechnical performance can repay for the investment in more advanced bolting solutions.

4.2 Self-drilling bolts installed on mechanised rock bolter

USR and SDB have been used several years in underground hard rock mines, typically using a mechanised bolting rig for installation. This combination delivers higher productivity compared to traditional solution such as cement-grouted solid rebar bolts (Bray et al 2019).

SDB installation process has three phases:

1. drilling
2. hollow bar insertion
3. post-grout.

Similarly to HBB, SDB nut can be tightened after resin is cured, but using feed thrust to push plate and mesh against the wall increases productivity to the maximum.

SDB could be the only working solution in poor, or very poor rock conditions. One-step or single-pass installation enables high quality installation in challenging rock conditions. The advantages are summarised in Table 6.

Table 6 Advantages of self-drilling bolts (SDB) installation process by a mechanised bolting rig

SDB and urea-silicate resin and mechanised bolting rig: advantages
Ideal for broken rock and rehab works Extension drilling capabilities
High productivity – fast resin Easy for automation

Disadvantages of SDB installation process are more expensive compared to HBB:

- higher resin consumption
- jammed rods in the case of uncoupling
- lower net penetration rate.

4.3 Rebar bolts installed on automatic bolting rig

Threaded rebar bolts are very popular worldwide. Some customers are not prepared to leave such a cheap and reliable product for a hollow bar. Still, the same customers would like to replace traditional polyester resin capsules with (pre-grout) pumpable resin. In fact, the shooting of resin capsules into broken ground may turn out to be difficult, with misfiring, lost holes and lost time. After several trials with pre-grout pumpable polyester mastic, a Sandvik DS mechanised bolting rig has been converted to USR and several pre-grout solid rebar bolts were installed and tested. Notably is the simplification of the installation process using a more fluid and pumpable USR resin, which means more productive bolting cycle. The initial test presents one bolt installation time close to 3 minutes. Advantages of this bolting solution are summarised in Table 7.

Table 7 Advantages of rebar bolts installation process by a mechanised bolting rig

(Solid) rebar bolt and urea-silicate resin and mechanised bolting rig: advantages
Improved cycle repeatability for better productivity especially in case of broken, fractured rock
More consistent load capacity results
Low-cost solution with standard steel element and minimum cost for USR resin
Possibility to convert existing bolting rigs to USR

Field tests in Canada verified the bond strength of USR associated with 22 mm solid rebar. Table 8 shows the loading capacity and the maximum displacement observed on 1.8 m long bolts installed in a small diameter borehole with pre-grout USR bulk injectable in very broken ground. Table 8 summarises the results of testing.

Table 8 Rebar Bolts pull-out test results on urea-silicate resin

Test no.	Bolt type	Embedment length	Hole diameter	Max. load (tonnes)	Max. displacement (mm)
Test 1	Threaded rebar 22 mm × 1,880 mm	Full length	31.7 mm	16.33	6.56
Test 2		Full length		16.33	12.35
Test 3		Full length		16.33	10.89
Test 4		457.2 mm		16.33	6.76
Test 5		457.2 mm		16.33	5.09
Test 6		457.2 mm		16.33	4.8

All specimens passed the required load, including the short embedment length ones. However, since not all solid rebars have the same rib design, we recommend performing similar test to verify the specific performance of the combination rebar/USR.

4.4 Cable bolts installed on automatic cable bolters and injectable resin

Cable bolts have been installed with pre-grout cement grout for several decades. Cement grout is really cost efficient. However, curing time is long and it's difficult to control its quality. USR fast curing time and relatively easy QC is therefore an appealing substitute of cement in mechanised cable bolters. USR gives earlier strength compared to cement and enables rapid re-entry to bolted area. Cables bolts can be pre-tensioned 10–15 t just 10 minutes after resin curing time. Advantages of using resin in cable bolting process is presented in Table 9.

Table 9 Advantages of cable installation process by a mechanised cable bolting rig

Newly developed DSI helical cable bolt and urea-silicate resin and mechanised bolting rig: advantages
Faster re-entry in the bolted area, with associate more efficient excavation process
Superior quality control of bonding element (especially compared to cement)
Clean, safe and self-contained system without need of manual intervention

USR installation methods replicates what used with cement (pre-grout) and can be performed from manual to greatly mechanised manner.

Being filler-free, USR associated to standard cable bolts deliver a weaker bonding strength when compared to cement. The research has been focused on seven-wire PC strands, and its external profile. Different wire diameters, wire surfaces and bulbs of different diameters were tested using same USR formulation. The target was to compare the specific bonding strength generated by 1 m of cable (before slipping out).

Average pull-out results in Table 10 shows the difference between standard and helical indented cables when using USR. The test setup was as follows:

- Resin type: DSI Mineral Bolt SLOW USR.
- Hole and embedment length: 1 000 mm, hole diameter: 54 mm.
- Resin curing time: 24 hours.
- Environment: Laboratory conditions at 20°C.
- Cable type and size: Newly developed DSI Helical indented with enhanced bonding features. 7 wire PC Strand diameter 15.2 mm and 17.8 mm, bulb size: 35 mm.

Table 10 Helical indented cable pull-out test results on urea-silicate resin

Test no	Description	Specific load capacity (tonne/m)
Test 1	Smooth cable 15.2 mm, 1 bulb × 33 mm	12.4
Test 2	Helical indented cable 15.2 mm, 1 bulb × 33 mm	23.0
Test 3	Smooth cable 17.8 mm	8.0
Test 4	Helical indented cable 17.8 mm, no bulbs	19.5
Test 5	Helical indented cable 17.8 mm, 1 bulb × 28 mm	21.6
Test 6	Helical indented cable 17.8 mm, 35 mm, 1 bulb × 35 mm	24.1
Test 7	Helical indented cable 17.8 mm, 35 mm, 1 bulb × 35 mm	28.4
Test 8	Helical indented cable 17.8 mm, 2 bulbs × 35 mm	28.6

New helical indented cable bolts, especially if associated with bulbs show a sharp increase in bonding strength. In these configurations, geotechnical expert can evaluate if USR can offer a real alternative solution to smooth cable and cement grout.

4.5 Hollow Bar and rebar bolts installed on face drilling jumbos

The latest innovation for face drilling jumbos is using injectable resin concept. Bolt types include three different types: SDB, HBB and solid rebar. The injection process is either pre-grout (HBB/SDB) or post-grout (rebar bolts). The innovation opens more bolt and grout chemical alternatives than traditional bolts that have been used on face drilling jumbos for a long time. Advantages of using resin in rebar installation is shown in Table 11.

Table 11 Advantages of solid rebar installation process by a semi-mechanised face drilling rig

Rebar bolts and urea-silicate resin and semi-mechanised face drilling jumbo: advantages
Higher installation quality compared to capsules
Full encapsulation
High productivity in fair – poor rock conditions

The installation method is semi-mechanised. Bolts are loaded manually onto drill feed at the beginning of bolt installation. This can be considered as one disadvantages of the system. The rest of the installation phases are mechanised. The two-feed system is used the following way:

- Hole is drilled by left drilling feed.
- Injection pipe feeder is moved to hole collaring by moving right drilling feed.
- Hole is grouted.
- Right drilling feed is indexed onto the hole.
- Bolt is inserted and tensioned.

Operators have certain time window to install bolt into the hole in case of pre-grouted solid rebars. Different setting time of resins can be tested if time window for bolt insertion is too short.

Ongoing trials on a Canadian site with a two boom DD422i Dual Control jumbo are installing 75 rebar bolts in 150 minutes using two booms simultaneously. This corresponds to an average overall rig productivity of 2–2.5 minutes per bolt, even using the relatively slow USR resin MI 100 (seconds). As operators' skill improve, faster resin with curing time of 55 seconds will be introduced with further improvements in productivity.

Resin tank and pump module is located at the rear part of carrier. Module is bolt-on, and all necessary resin components are in the module. Injection hose feeder system is mounted onto right drilling feed. Hoses are connected from resin tank and pump module to feeder system. Both of systems are shown in Figure 7.

Figure 7 Sandvik DD422i-DC face drilling jumbo equipped with urea-silicate resin pumping kit

4.6 Self-drilling bolts installed on face drilling jumbos

Threaded rebars have been used on face drilling jumbos with capsules for a long time. Now it will be possible to use SDB and injectable resin as alternative bolt types on jumbos. Process is semi-mechanised like for solid rebars and other bolt types. SDB is manually loaded onto the right drilling feed. Installation process phases are:

1. Hole is drilled by SDB.
2. Hole is injected through hollow core of SDB using an injection head (Figure 8).
3. Bolt is tensioned by left drilling feed.

Table 12 shows some advantages given by SDB bolt installed by face drilling jumbo. All different application and methods guarantee high quality installation when using SDB and injectable resin. Control system looks after entire injection and bolt insertion process. Super-fast resin can be used to achieve the highest productivity. Super-fast resin also creates the opportunity to use SDB with mesh, similar in the way conventional friction bolts are used. Disadvantages are related to manual bolt handling processes and higher products cost compared to another bolt types.

Figure 8 Sandvik DD422i-DC face drilling jumbo self-drilling bolt injection head

Table 12 Advantages of self-drilling bolts (SDB) installation process by a semi-mechanised face drilling rig

SDB and urea-silicate resin (USR) and semi-mechanised face drilling jumbo: advantages
The highest productivity on super-fast USR
Full encapsulation
Only working solution in poor–very poor rock conditions

5 Conclusion

Modern ground support solutions require and integration approach where all elements are optimised and fit for each other. This study presents a comprehensive R&D program where bulk, injectable USR resin are fully integrated with various drilling rigs, rockbolt installation systems, a selection of ground support elements (bolts or cables) and digital data solutions.

Sandvik believes in this approach and has started more intense cooperation between different divisions toward a common integrated solution. Sandvik believes that rig-steel-chemical elements integration is essential to improve safety, productivity, and lower total cost of operation in ground support.

Sandvik USR-based systems are good examples of the operational results generated by integrated solutions. USR-based systems deliver enhanced safety and productivity with several installation methods (based mechanised bolting rigs and face drilling jumbos) and a large range of bolt types (SDB, HBB, rebar bolts and cable bolts).

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