Intersection reinforcement with self-drilling anchors for improved productivity at Kanmantoo

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ABSTRACT

An improved ground support method for development intersections, wide spans and stope brows was implemented at Kanmantoo mine. The method uses a jumbo to simultaneously drill and install self-drilling anchors (SDAs) to depths from 4.5 m to 7.0 m. Resin is subsequently pumped into each SDA using a specially designed integrated tool carrier basket, with plating occurring within 10 minutes due to rapid resin cure. This methodology means that SDAs can be installed rapidly due to reduced process steps and wait times with reduced hazards to personnel.

Cablebolts are used extensively in underground mines to reinforce the ground in wide spans, such as at intersections and stope brows. The flexible cablebolt tendon allows for a long, continuous and high-capacity reinforcing element to be inserted into the rock. A common cablebolt installation practice at Australian underground mines that do not utilise a mechanised cable bolter, is for cablebolt holes to be drilled by a jumbo or long hole rig, hand installation and grouting by a service crew, then plate tensioning following a grout curing wait time of typically 12 to 24 hours. This process involves multiple separate labour-intensive work processes and results in reduced availability of priority headings.

This paper discusses the development history of vertical SDA use in wide spans at Kanmantoo mine. The installation process is fully described, including aspects such as reliable in-hole coupling of SDAs, resin selection and pumping aspects. A cost benefit assessment, and a case for ground stability are presented to compare cablebolt use to SDAs in development intersections.

INTRODUCTION

Deep ground support installation is often required within development intersections at Australian Mines. While many of the larger mines use dedicated cablebolting rigs, there are a greater number of smaller mines that install cablebolts without these machines, primarily due to the capital cost involved and the periodic need. These mines use jumbos (development drill rigs) to drill holes and service crews for the hand installation, grouting and plating of cablebolts. This practice involves multiple labour intensive work processes and causes reduced availability of priority development headings. This is mainly because cablebolts are used as the long reinforcement element with a grout encapsulation medium. The cablebolting process slows down development advance rates at these mines and requires multiple work teams to complete.

Speeding up intersection ground support installation has significant benefits to an underground mine. The benefits of increased efficiency in this area were identified as an implementation priority by Hillgrove Resources Limited at their Kanmantoo copper mine in South Australia.

The use of SDAs at intersections instead of cablebolts at Kanmantoo has resulted in significant improvements such as faster priority heading advance. The SDAs are installed with a jumbo then resin filled by a service crew. Reinforcement of intersections is achieved by installing high tensile strength SDAs to reinforcement depths of 4.5m or 7m.

BACKGROUND

The application of long reinforcement for stope support with '*long flexible cables has been under continual development since the early 1970's*' according to Fuller (1983). Historically, the wide spans formed at intersections were not always supported with cablebolts as deep support. Risk mitigation has led to this becoming adopted as standard practice. Potvin and Nedin (2003) released a reference manual for management of rockfall risks in underground metalliferous mines and stated that '*Intersections, or areas where two or more drives connect, may require special consideration and specific ground control measures. Larger spans are exposed in intersections which can allow large wedges to daylight. Some mines require that all intersections be systematically cable-bolted either during, or immediately after being mined*'.

Usually, patterns of cablebolts are installed in the backs with the total number designed to reinforce and hold a loosened zone that accounts for the width of the intersection. This method of intersection design, referred to as the parabolic arch methodology, has been practiced by some in the mining industry for well over 20 years and was more recently documented by Potvin and Hadjigeorgiou (2020).

The utilisation of SDAs in mines has been occurring for many years particularly in portal development and at major infrastructure locations. In hard rock mines, SDAs are used for specialised applications such as perimeter spiling bars for development through backfill and in poor ground conditions. Until now, use has not extended to reinforcing in the vertical plane as there was no way to hold the progressive segments up a vertical or inclined hole while drilling. The use of SDAs became more compelling with the development of commercially available pumpable thixotropic resins. The 20 minute cure time of these resins eliminated the need for 12 to 24 hour cure times associated with using cementitious grout. Thixotropic resins allow single pass pumping of resin through the SDA and back to the hole collar along the annulus without the need for wadding or breather tubes, thereby simplifying and improving the quality of the installation.

A new mine in early development may only have a development jumbo drill available for use. In this situation jumbo operators use a range of techniques to drill holes of suitable length for hand installed cablebolts. These techniques vary from stabbing extension steels with the second boom, to the use of pitot jaws on booms (generally without the equipment suppliers' recommended rod handler) and other iterations of these with varying levels of practicality and safety. Changing a jumbo that is setup to drill and support a face so it is ready to drill cablebolt holes includes several steps, such as using different drill rods, adding pitot jaws and a rod handler, taking several hours.

Small mines in their production phase generally migrate from using the jumbos to drill intersection support to using production drills. This solves the inefficiency and safety issues of using a jumbo but it reduces the efficiency of the production drills. Production drills are required to tram to the intersection for a relatively small amount of drilling, often significant distances from the areas where they are undertaking production drilling.

Drilling these deeper holes with either of these drill types then requires cables to be installed, grouted, plated and tensioned manually, typically from tool carrier baskets. There is significant evidence in the industry of ongoing issues with this process, which has typically resulted in impact and strain injuries, grout burns and eye injury. In addition, logistics associated with each of these processes and the associated minimum curing time of the cementitious grouts used, typically leads to delays in critical development headings of several days. Miners accordingly schedule their mine development allowing for the impact of these delays on the critical path mine access development.

Larger mines mitigate the above requirements with the operation of cable bolters, however this has the associated costs and requirements of dedicated capital machines and specially trained operators. Ideally, operators would like to install deep support elements in intersections and wide spans with development drills without the issues and delays of cablebolt installation.

KANMANTOO MINE DECISION MAKING PROCESS

The Kanmantoo copper mine in South Australia, operated by Hillgrove Resources, commenced underground development during 2021 following a successful period of mining within the Kanmantoo open pit. Hillgrove Resources decided to install SDAs in development intersections instead of following the standard industry practice of using cablebolts. It was believed this change was worth pursuing due to the improved cycle times related to reduced wait times and reduced work tasks for each intersection support cycle.

Process Simplification and Time Gains

A development intersection that is reinforced by hand installed cablebolts requires several separate work processes, including drilling of the cablebolt holes, installing the cablebolts and grouting, a wait time for grout cure and plating/tensioning. This intensive ground support cycle is often repeated a second time when the designer has determined that second pass cablebolts are required for a wider spread of cablebolts throughout the intersection, as shown in FIG 1.

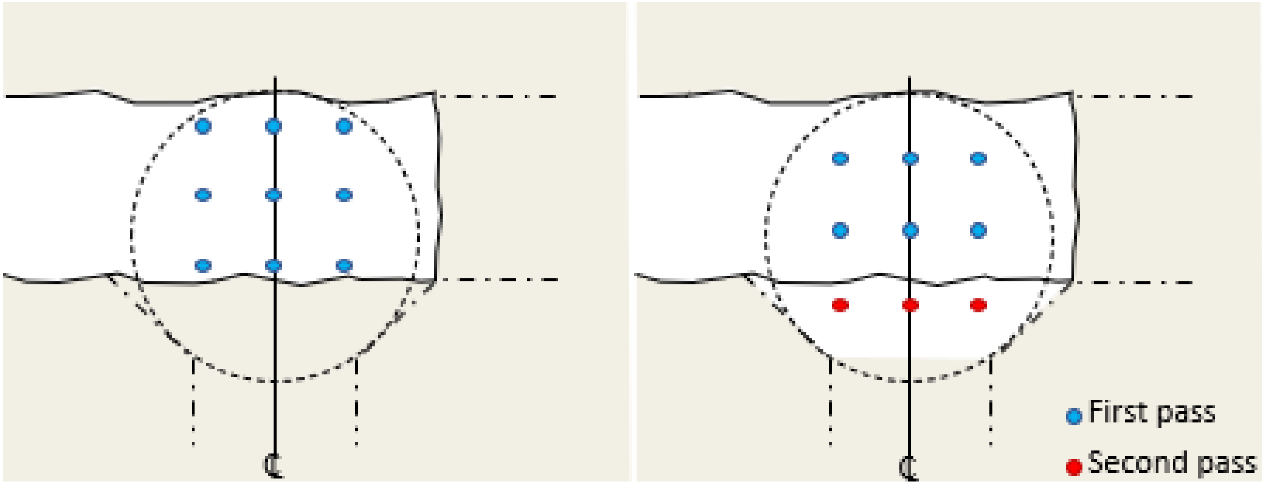


FIG 1 – First pass and second pass intersection cablebolting

When using SDAs instead of cablebolts the number of work processes reduces to drilling the SDAs and pumping the resin. Wait time is not required due to the speed of resin strength gain, and plating/tensioning the SDAs is completed by the jumbo when drilling the next face. This reduces the number of work steps from four to two during single pass intersection support cycles and decreases the time required for long support installation from as much as 24 or 36 hours to 9 hours. This is summarised in FIG 2. Cablebolts are prone to unravelling prior to plating when close to blasting, making the subsequent plating and tensioning unpractical. The minimal protrusion required for the SDAs make them far less susceptible to damage from adjacent blasts compared to cablebolts.

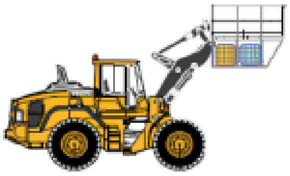
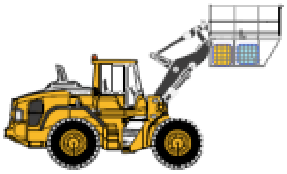
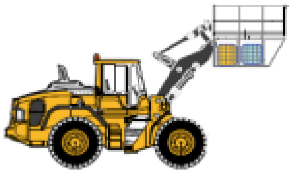
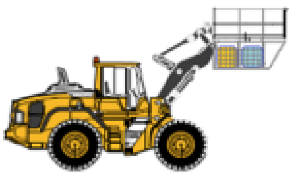
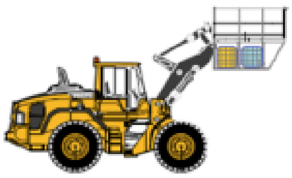
DEEP GROUND SUPPORT				
	Current Process in Small Mines	**Typical Duration** (Hours)	**Planned Process at KCM**	**Typical Duration** (Hours)
DRILL HOLE	Drill Holes with Jumbo 	6	Drill Holes with Jumbo 	4
INSTALL ELEMENT	Install Cables by Hand 	4	Install SDA's While Drilling 	0
SECURE	Grout Cables by Hand 	5	Resin Inject SDA's 	3
CURE		12		0
PLATE	Plate and tension after Cure 	2	Plate SDA's 	2
	Total Time	**29**	Total Time	**9**

FIG 2 – Intersection long reinforcement work steps and timings (KCM – Kanmantoo Copper Mine)

Costing Considerations

A costing scenario of reinforcing an intersection with cablebolts verses SDAs is provided in Table 1. This information breaks down the costs for each of the work steps described in FIG 2 for a standard intersection with eight 6 m long twin strand cablebolts compared to eight 4.8 m long 38 mm SDAs. This is based on the mines owner operator costs and does not allow for fixed overheads or contractor profit margins. Each element in the cost comparison considers the ownership capital cost of equipment, the operating cost of that equipment, the consumables costs and labour required.

TABLE 1 – Cablebolt and SDA costing comparison for intersections

Cost Comparison	Conventional Cablebolts	SDAs
Logistics	$520	$250
Drilling	$4,250	$3,010
Element Supply	$2,530	$1,927
Element Installation	$1,700	-
Grouting / Resin Injection	$3,682	$3,270
Plating / Tensioning	$840	$330
Total Cost	**$13,522**	**$8,787**
Unit Cost (per m of installed element)	**$282**	**$229**

The costing comparison shows that an intersection can be reinforced using SDAs for significantly less than using cablebolts.

A further significant saving that is not captured in the direct cost comparison is the reduced time required to fully support an intersection when using SDAs. The SDAs can be fully installed in less than a shift compared to a minimum of two shifts required for conventional cablebolts. This is a material difference for a rapid development decline which pulls forward the development completion date and subsequent mining. This approach can be fully appreciated when managing a single heading decline which has an entire fleet of gear and team of personnel waiting for 12 to 24 hours for grout to cure in their only development heading.

SDA and Resin Selection

SDAs are a hollow steel bar with a threaded outer surface. The sacrificial drill bit uses the flushing holes to allow resin flow through the bit, once installed. Sections of SDA can be joined with a high strength internally threaded coupling. The SDA is filled with resin by connecting onto the installed SDA at the collar and pumping resin through the SDA’s hollow core. The resin flows through the bit and back down the drill hole annulus to the collar, as shown in FIG 3. Full encapsulation is achieved, and this results in a stiff bolt suited to static ground conditions.

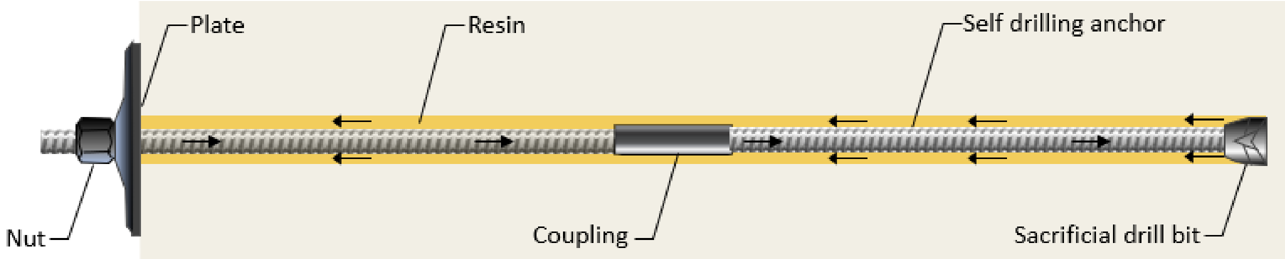


FIG 3 – Conventional SDA, with arrows showing resin flow direction

SDAs used for supporting intersections are available from ground support or drilling consumable supply companies. At intersections, Kanmantoo mine use 2.4 m lengths of the R32 or R38 SDA, which are coupled together during installation for 4.8 m long SDAs (4.7 m effective length, with 100 mm extruding from the hole). Specifications for the SDAs are shown in Table 2.

TABLE 2 – SDA specifications

SDA Description	R32	R38
External diameter (mm)	31.1	37.8
Internal diameter (mm)	18.5	19
Yield load (kN)	230	400
Ultimate tensile load (kN)	280	500
Ultimate load strain (Agt%)	≥5%	≥5%
Weight (kg/m)	3.2	5.85

The SDA steel stretches under load, as shown by having an ultimate load strain (Agt%) value of over 5 %. This is a measure of the total elongation at maximum load, excluding the plastic deformation of the steel. It provides a better indication of rock bolt stretch under normal working loads, rather than considering the total elongation which includes consideration of the plastic deformation prior to failure. Cablebolts are often described in terms of their total elongation to failure, with typical values of 6.5 % strain for 600 mm test lengths of 15.2 mm cable. SDA bar compares favourably to this and was concluded by Kanmantoo to have suitable steel properties for use as long reinforcement.

Site trials were conducted on five different brands of two-part thixotropic resin. All showed suitable strength and pumpability characteristics during trials. Some were temperature sensitive for pumpability and some had fast cure times which was a challenge when pumping SDAs over 9 m long. Master Builders Solutions provided MasterRoc® RBA380 an adaptive curing (3-5 minutes) resin and worked with Kanmantoo to optimise the static mixer matched for their resin product. Samples of resin were taken during trials which enabled cure times to be measured and later testing for strength using UCS testing.

Ground Stability Considerations Using SDAs

The local mine ground conditions at Kanmantoo are considered static with competent rock and low to medium stress conditions. Static conditions for ground support design are essentially the same as “normal conditions” which were defined by Potvin and Hadjigeorgiou (2020). They described normal conditions as strong rock, with ‘good’ rock mass quality and mining induced stresses that are lower than the amounts required to cause initial visual signs of stress damage, such as face spalling or shotcrete cracking.

Kanmantoo uses the parabolic arch methodology for justification of the long ground reinforcement at intersections. The SDA types used at Kanmantoo (R32 and R38) were selected to balance ease of handling and reinforcing capacity. The tensile strengths of the R32 and R38 SDAs match relatively well with single strand and twin strand cablebolts respectively as shown in Table 3.

TABLE 3 – Nominal load bearing properties for SDA and cablebolts

Load Bearing Properties	Unit	6m x 15.2 mm Bulbed CB	R32 SDA	6m x 15.2 mm Twin strand Bulbed CB	R38 SDA
Nominal yield load	[kN]	250	230	500	400
Nominal ultimate load	[kN]	265	280	530	500

The elongation properties of the SDA bars describe that the bar steel will stretch, but the way the bolt behaves is different to a cablebolt, mainly due to stiffness of a fully installed SDA. The coarse thread on the outside of the SDA locks the bar in place within the resin and following installation there is limited free length of SDA bar, except for a very minor amount at the collar depending on the seat of the plate against the excavation surface. A hand installed cablebolt has free length at the collar due to cotton wadding, and a loaded cablebolt is more likely than an SDA to exhibit some amount of debonding at the grout to bolt interface when under load. Both SDAs and cablebolts can expect to have some system elongation due to movement at the plate. Cablebolts are more capable of absorbing ground movement prior to failure than a fully encapsulated SDA. This concept is described in FIG 4.

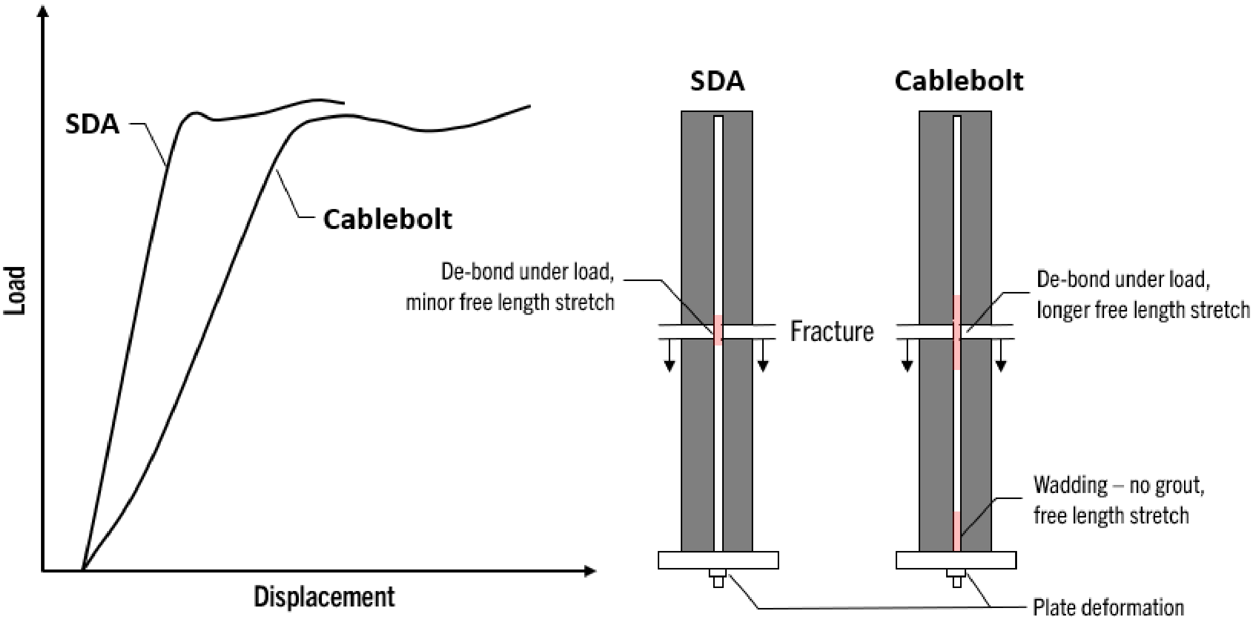


FIG 4 – Conceptual diagram of SDA and cablebolt displacement under load

When the SDA ground support system is required to manage high stress conditions and exhibit greater system ductility, there are commercially available SDAs with smooth, annealed tube sections, intended to absorb energy by allowing the steel to stretch.

Intersection spans reinforced with cablebolts often use 6 m cable lengths at mines with standard intersection dimensions. 6m cable lengths are required due to the anchorage needed to lock the cable into the ground beyond the parabolic arch loosened zone, as shown in FIG 5. The required anchorage length for bulbed cablebolts, or the critical embedment length, is usually thought to be about 2 m. A 2 m cable anchorage length allows for two bulbs on each cable of a twin strand to be locked in place beyond the loosened zone. It also adds extra conservatism for variable grout mix strengths and poor grout encapsulation at the end of the cable where air pockets can form while grouting. The SDA is a more reliable system for full encapsulation at the end of the bolt in the anchorage zone. For typical intersection sizes at Kanmantoo mine such as a 11 m intersection span (and a 3.7 m high parabolic arch loosened zone), 4.8 m long SDAs (two 2.4 m long bars coupled together) provides 4.7 m of SDA embedment, with 1 m of SDA in the anchorage zone at the highest part of the parabolic arch.

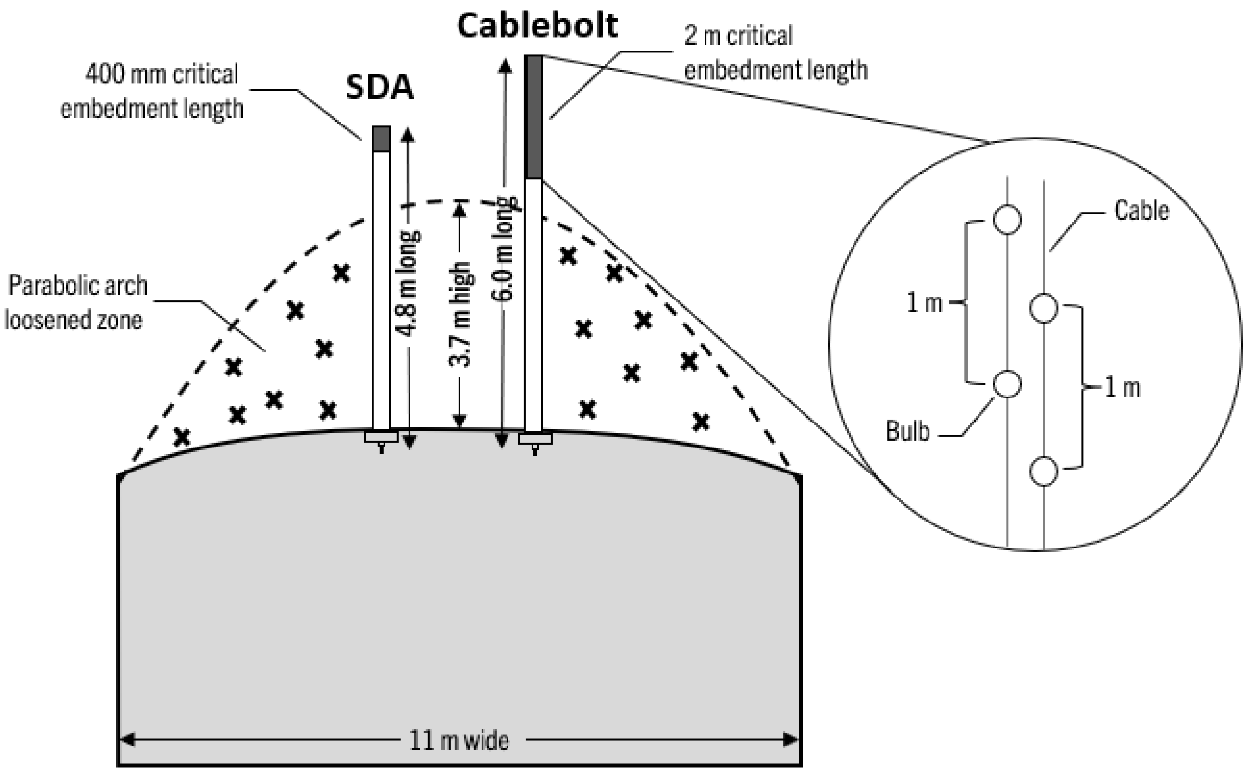


FIG 5 – Conceptual wide span cross section of SDA and cablebolt critical embedment lengths

Field Tests

SDA short encapsulation pull tests to determine critical embedment length were undertaken at Kanmantoo with results shown in Table 4. During the testing it was evident that SDAs achieved high strengths up to the SDA steel tensile strength with very short encapsulation lengths. SDA steel tensile capacity was reached in 300 mm to 400 mm of resin encapsulation.

TABLE 4 – Minimum encapsulation test results for R32N SDA

Bolt #	Encapsulation	Max Load		Residual Load		Failure Mechanism
	(mm)	(kN)	(t)	(kN)	(t)	
1	300	220	22	80	8	Resin / bolt Interface – pulling bit through
2	300	310	31	260	26	Resin / bolt interface – pulling bit through
3	400	380+	38+			Bolt tensile failure
4	400	260	26	250	25	Resin bolt interface – pulling bit through
5	500	380+	38+			Bolt tensile failure
6	500	350	35	230	23	Resin Bolt Interface – pulling bit through
7	600	360	35	210	21	Resin Bolt Interface – pulling bit through
8	600	380+	38+	210	21	As 7 plus Nut failure over SDA thread

Annulus width is the distance from the outside diameter of the SDA to the hole wall. Trials completed with vertical clear Perspex tubes by PYBAR at Dargues Gold Mine showed that at large annuluses there is potential for resin to free fall and not fully encapsulate the SDA. The testing setup is shown in FIG 6. It is recommended that 51 mm holes for R32 SDA’s and 64 mm holes for R38 SDAs be the maximum size used to prevent the risk of incomplete encapsulation. At these dimensions the thixotropic resin sticks to the drill hole walls while returning down the annulus, slowing the resin flow and preventing resin free fall.

FIG 6 – Resin encapsulation tests using Perspex tubes

INSTALLATION OF INTERSECTION SDAS

SDAs can be manufactured to any length, typically 2.4 m long for development drills or 1.8 m long for production drills. They can be manufactured with prefabricated bushes and couplings to assist with ease of installation. Kanmantoo use the SDA LOCK™ manufactured by ME Safe to suspend the SDA in the hole once drilled prior to resin encapsulation. The SDA LOCK™ is a retainer device fitted to the SDA between the drill bit and a shoulder member (either a swage element or a coupling as shown in FIG 7) enabling the SDA to be installed as per the standard procedure.

During drilling, the SDA LOCK™ abuts against the shoulder member. The SDA can rotate independently within the SDA LOCK™ (FIG 7, Diagrams 1 & 2), and the drill bit rests on top of the SDA LOCK™ retaining the SDA in the hole with the folded down tabs providing the retaining force (FIG 7, Diagram 3).

During the development of the SDA LOCK™, significant trialling was undertaken applying different loads in varying rock types to build a database of their reliability. Installation was completed with a Sandvik DD 421 jumbo using the second boom to stab and hold the installed SDA while breaking the coupling at the shank to add subsequent lengths of SDAs. A combination of 4.8 m, (two lengths) and 7.2 m, (3 lengths) SDAs have been installed to date depending on intersection span and design.

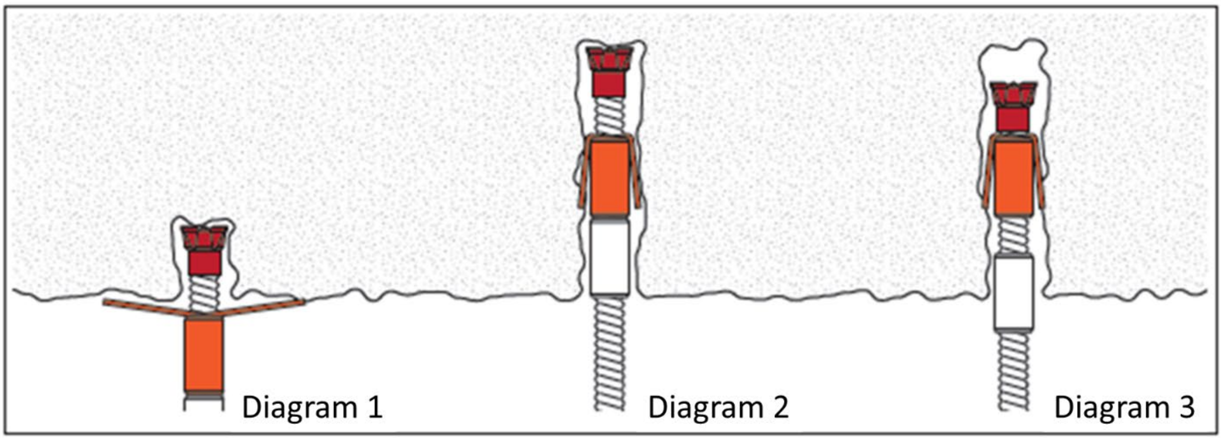


FIG 7 – SDA LOCK™ diagrams of drilling installation

Best practice SDA installations commence from the furthest to nearest SDA in the drive so no person travels under them, reducing the likelihood of exposure to a failed spring or steel element. If for some reason the SDAs can not immediately be resin encapsulated, they can be secured via chain to the mesh (or rock bolt plate flanges, if available) with captive caps as is often practiced with cablebolts during installation and grout curing.

Once the SDAs have been installed, they can be resin encapsulated. Kanmantoo's approach is to keep this process independent of the drill, allowing it to return to its primary role of drilling and supporting development headings. A gear pump is used to pump a two-part thixotropic resin up the centre hole of the SDA and back down the hole via the annulus. The two parts of the resin are pumped separately and only mixed in a static mixer at the head that is attached to the SDA. This means that there is minimal resin wastage and clean-up. Some resins can be temperature sensitive, and manufacturers should be consulted when they are used in cold temperatures or conditions of cyclic temperature.

The use of resin in this method significantly reduces the likelihood of cement dust or grout entering operators' eyes which is common in existing practices and has led to most sites having diphoderine or eye washes on the mixing gear and mandatory goggle use. Grout is commonly pumped into holes under pressure using poly fittings and low-quality hose which can easily blow out when poorly mixed grout is used or obstructions in filler or breather pipes occur. These blow outs can lead to eye injury, ingestion, and skin rashes. Resin pumping is done using high quality, fit for purpose designed hoses and pressure relief valve systems to prevent such occurrences.

The small tanks for part A and part B of the resin, the gear pump and associated hosing fit into a tool carrier basket. Kanmantoo mine have fabricated a high lift basket with the tanks and pump on the lower deck with the controls on the upper deck, allowing resin injection to be completed without the trip hazards in the basket of the pump and tanks. This same setup can be used for Kanmantoo's thin spray on liner (TSL) application, making the whole setup multipurpose and pumps interchangeable across both operations, as shown in FIG 8.

FIG 8 – SDA and TSL basket used at Kanmantoo Copper Mine

CONCLUSIONS

The SDA and resin solution implemented at Kanmantoo mine provides a dependable deep support system for wide spans. Flow on improvements to safety, cost and efficiency have resulted in the use of resin filled SDAs at Kanmantoo in intersections and wide span areas of the underground mine.

ACKNOWLEDGEMENTS

PYBAR Mining services should be recognised for initiating this project and for supporting SDA trials at multiple mines including; Carrapateena, Henty, Dargues and Thalanga. The miners at these sites along with Warren Attwell and Sam Lennon at Kanmantoo are acknowledged for their input and guidance and having the patience in the small hours of the night to get the system just right. Strata Consolidation have had a significant impact on the development of this system with the use of their resin pumps, their pumping experience and provision of professional pumping services over several years to get to this point. Quarry Mining Services and the teams at DSI and Split Set Mining Systems have also greatly helped in providing SDAs for trials and input into the process.

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