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Spin to Stall Bolting Systems–a Review of Validation Standards

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SPIN TO STALL BOLTING SYSTEMS – A REVIEW OF VALIDATION STANDARDS

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ABSTRACT: Originating from South African practices, spin to stall bolting systems have seen an increasing focus within Australian coal mining operations over recent years. The primary driver for spin to stall applications is the goal of improved bolting cycle times, with a secondary benefit being simplified installation practices for roof bolting operators. These outcomes are seen as one part of a broader opportunity to improve overall underground mining efficiencies and extraction rates.

Spin to stall bolting methods represent a divergence from long standing resin installation practices, with the resin 'hold' or 'curing' time being eliminated from the installation cycle. The bolt can therefore be spun continuously under thrust through the length of the resin cartridge, with rotation continuing until the resin polymer matrix cures and hardens, the bolt torque drive releases, the nut is advanced on the thread and the bolt is ultimately pre-tensioned until rotational stall of the drill rig motor occurs. However, concerns remain that as the resin cures under polymerisation, significant loading is immediately placed onto the resin matrix before the polymer chains have fully formed, with the subsequent risk of damage to the interfaces between the bolt, resin and borehole – ultimately weakening bolt load transfer into the strata.

The divergence from standard resin bolting practices has also led to changes in product validation methods, with validation practices being created specifically for spin to stall testing. This paper provides a detailed analysis of the technical parameters that govern spin to stall installations, as well as an assessment of validation techniques, including the inherent difficulties associated with underground testing. The arising question is whether current validation practices actually address all aspects of bolt performance, with some areas for concern being potentially masked regarding bolt load transfer. Finally, this paper offers potential improvements for spin to stall validation methods, in an attempt to further progress this area of work within the industry.

INTRODUCTION

The primary function of roof bolting is to deliver one or more of four main support strategies – simple skin support, suspension of a thin roof layer from a massive bed, beam building of laminated strata and keying of highly fractured and blocky rock mass (Canbulat *et al.*, 2005). Resin bolt performance, whether conducted as a standard installation, or as a spin to stall system, is ultimately about achieving the required geotechnical outcomes. Load transfer from the bolt, through the resin annulus and into the strata is a critical aspect of all four support strategies – providing transfer of forces from the mechanical support elements into the ground.

Traditional resin bolting practices employ a 'hold' time to permit polymerisation and curing of the resin. The hold time immediately follows mixing of the resin, and involves a period where there is no rotation or pre-tension applied to the bar. The bar is momentarily held in a static state – this enables the resin to cure around the profile of the bolt as well as adhere to the surface of the borehole. The resin curing time permits the development of polymer chains during chemical transformation of the two component resin cartridge. Longer polymer chains provide greater final strength of the resin matrix that has formed. The

length of the polymer chains is a function of the curing time – greater hold times permit longer polymer chains to form and subsequently produce stronger cured resins. There are two predominant installation practices that involve a hold time sequence. Australian roofbolting practices typically employ a combined spin and thrust through the resin, with additional rotation at the back of the hole for final mixing and then a final hold time to ensure correct polymerisation. After the hold time, the bolt is then pre-tensioned (Hillyer *et al.,* 2013). This method produces greater mixing at the base of the resin column, and proportionately less mixing towards the top of the bolt.

A more conservative approach is typically taken in the USA coal industry, where the bolt is firstly thrust to the back of the hole without any rotation. Following full insertion, the bolt is then rotated to mix the resin. Following mixing, a hold time is finally employed to ensure correct polymerisation, before pre-tensioning of the bolt. This method ensures even mixing of the resin through the entire height of the resin column. Other variations of this method include slow rotation during bolt insertion, then a period of higher rotation to ensure correct mixing of the resin.

Spin to stall systems have a documented history of research dating back to the late 1990's, with various practices that had originated from within South African coal mines (Canbulat *et.al,* 2005). The main divergence from traditional installation methods is the removal of the hold time for spin to stall. However, multiple concerns were also raised during that same early assessment period regarding damage to the bonding between the bolt and the resin, including the need for increased roof bolt densities to compensate for weaker load transfers (Bigby *et al.,* 2004 and Canbulat *et al.,* 2005). Within the context of the developmental history of spin to stall bolting methods, the primary purpose of this current paper is to provide a review of the key parameters and methods of testing for spin to stall applications. While there is a growing body of work in the industry, a comprehensive standard remains to be more fully established.

MIXING AND LOADING SEQUENCES – SPIN TO STALL

Spin to stall practice places a demanding sequence of load immediately onto the resin during polymerisation and curing, within a comparatively rapid timeframe. For a dual speed resin, commonly used to provide pre-tension into the steel bolt element and generate compressive forces into the strata, a number of technical complexities arise. The 'fast-set' component of a dual speed resin cartridge is of course in the upper portion of the borehole. As the bolt rotates and thrusts, mixing from the bottom-up through the resin cartridge, it is the fast-set component that actually mixes last, but must react and harden first. Therefore, the fast-set component must react rapidly in order to take the sudden sequence of applied loads as the resin commences its transformation into a solid.

Firstly, the fast-set resin must adhere to and rapidly 'grip' the steel bar profile, to suddenly arrest rotation of the roof bolt. During release of the shear pin, rotational torque is transmitted directly onto the resin annulus at a value that is predetermined by the mechanical properties of the pin – as indicated in Figure 1a. This sudden arrest of rotational torque creates torsional shear forces through the entire resin annulus, including the associated interfaces with the bolt and borehole. Of course, lower shear pin release torques will produce a lower torsional force on the resin matrix, however, higher shear pin values are typically required to drive the bolt and mix the resin to the back of the hole.

For a 1.8 m long M24 roof bolt, within a 28mm borehole and utilising a 1000mm long resin cartridge with a 50:50 fast-set to slow-set ratio, the total resin volume can theoretically exceed 1700mm of encapsulation length – and the fast-set component is assumed to be at least 850mm long in the upper resin column. The applied release torque of the drive nut has been reported to be as high as 244 Nm (Emery *et al.*, 2015). Based on an average roof bolt core diameter of 21.8 mm, a torsional shear force of 22,385 N is generated at the bolt-resin interface. For the 850 mm length of fast-set resin, the bolt-resin interface has a cylindrical surface area of approximately 58,221 mm^2 (excluding rib deformations). These results in a torsional shear stress applied to the resin interface of 0.384 MPa, assuming a uniform

gel time across the 850 mm fast-set column length. If the fast-set gel time is not uniform, for example, if applied only over 500 mm of resin, then the torsional shear stress becomes 0.654 MPa (or 6.67 kg/cm^2). Secondly, the fast-set resin must now take the pre-tension loads applied to the bolt – with the nut advancing on the thread and tensioning the bolt against the strata. This pre-tension force is also applied directly to the fast-set resin component, creating an axial shear force along the entire length of the hardening fast-set resin column. However, in combination with the axial force, a further torsional force is applied to the bolt associated with rotational tightening of the nut. So, the 'pre-tension' load is actually a combination of axial and torsional loads.

For an axial pre-tension load of 6 t ($\approx$ 60 kN), a torque of approximately 200 Nm is applied during final tightening of the M24 nut. Applied across the 850 mm fast-set resin column, the torsional shear stress is 0.315 MPa and the applied axial shear stress is 1.031 MPa. The combined torsional and axial shear stresses induced during pre-tension totals 1.346 MPa (or 13.73 kg/cm^2) at the resin-bolt interface. However, for an axial pre-tension load of 8 t ($\approx$ 80 kN), a torque of approximately 270 Nm is applied during final tightening of the M24 nut. Across the 850mm fast-set column, this will induce a torsional shear stress of 0.425 MPa and an axial shear stress of 1.374 MPa – a combined shear stress of 1.800 MPa. For a non-uniform fast-set gel time, if applied only over 500 mm of resin, the combined axial and torsional shear stress at the bolt-resin interface becomes 3.059 MPa (or 31.19 kg/cm^2).

So, during polymerisation and curing of the resin, two significant loads are applied to the resin-bolt interface - an initial torsional shear stress that is induced during pin breakout of the nut and being potentially of the order of 0.654 MPa, followed by combined axial and torsional shear stresses that are induced during pre-tension and being potentially of the order of 3.059 MPa. Subsequently, it can be seen that the stresses induced during pre-tension are much more significant than the stresses induced during nut breakout by a factor of almost 4 to 5 times.

(a)   (b)
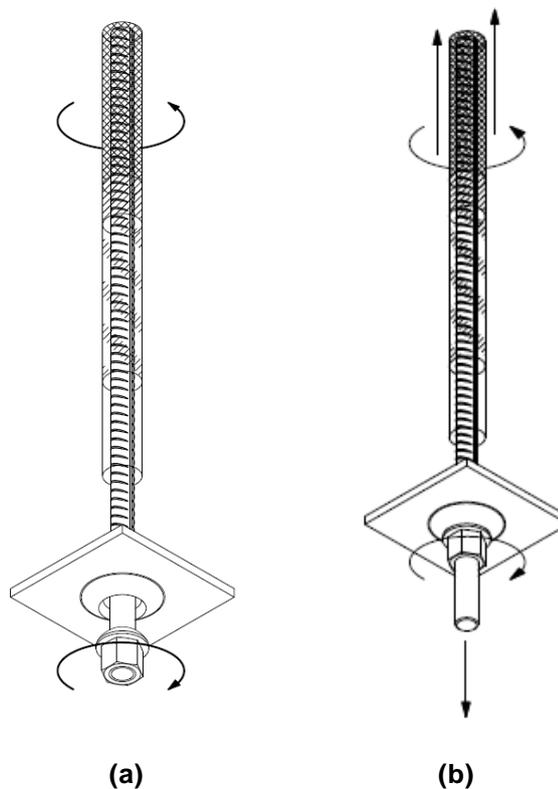
Figure 1: Forces induced on resin during spin to stall installations

The 'slow-set' component of the resin cartridge is positioned towards the bottom of the borehole. The slow-set component is designed to permit pre-tension and elongation of the roof bolt steel, before the slow-set resin finally cures and hardens, locking in the bottom half of the bolt profile onto the now

pre-tensioned bar. As the bolt rotates and thrusts, mixing from the bottom up through the resin cartridge, it is the slow-set resin that begins to mix first. The slow-set component of the resin will therefore see continued mixing for the entire duration, until the fast-set resin finally arrests rotation of the bolt. As a result, the slow-set resin risks 'over-mixing', where the polymer chains have moved beyond full formation and are subsequently broken down by continued rotation of the bolt. The result of over-mixing is solid resin that is weakened and brittle in appearance, dramatically reducing load transfer through to the strata.

Resin mixing levels – spin to stall

Various methods of bolt installation will produce different levels of mixing along the resin column. For combined spin and thrust through the resin, the amount of resin mixing will proportionately reduce through the height of the resin column. This can be represented by mapping out the cumulative number of revolutions of the bolt per unit height as the bolt advances through the resin column, as represented in Figure 2. This diagram assumes a constant rate of feed and rotation, then a period of rotation at the back of the hole, or rotational dwell, with the bar fully advanced in the borehole.

The timing sequence through spin to stall installations subsequently becomes critical. The bolt must thrust and mix at a rate where it is at the back of the borehole before the fast-set component begins to cure – otherwise the bolt will not fully insert and pre-tension. The speed of bolt insertion is further complicated by the potential for over-pressurisation of the fluid resin and the subsequent elevated risk of hydraulic fracture and loss of resin at the top of the bolting horizon (Evans 2015). There must also be a period of continued rotation on full insertion of the bolt to ensure mixing is adequate at the top of the borehole. So, the timing sequence for curing of the fast-set resin component must permit thrust through the resin column, as well as rotational dwell at the back of the hole, but avoid over mixing of the slow-set component – there is therefore a critical rotational dwell time, also shown in Figure 2.
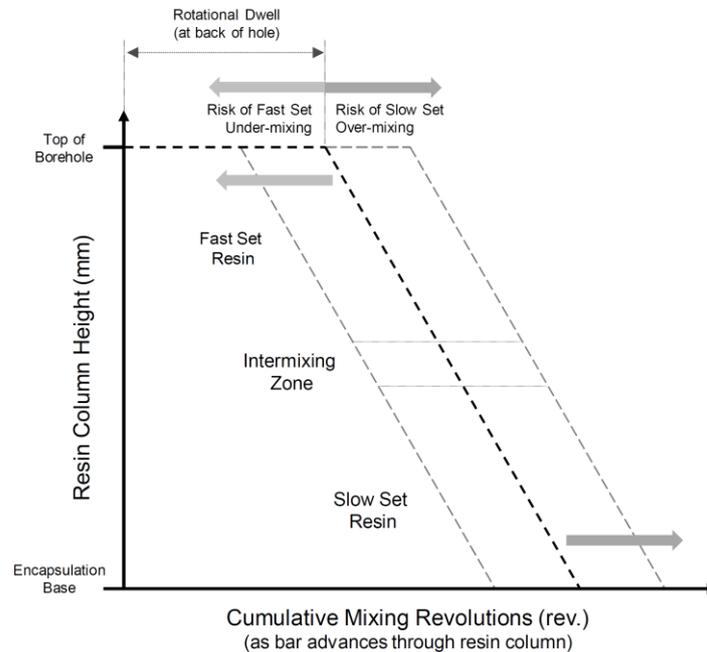
Figure 2: Cumulative mixing revolutions through the resin column

For spin to stall applications, the rotational dwell time is actually governed by the fast-set resin curing time, and not by the mechanical cycle of the drill rig. Correspondingly, there is a greater degree of uncertainty in mixing due to variation in the curing time of the fast-set resin – given variances in strata lithology, ground temperatures, resin storage conditions and also equipment variables for thrust and rotation. Variation in the fast-set gel time will therefore cause variation in resin mixing times, ultimately

affecting the quality of the installed resin and the corresponding load transfer performance (Aziz *et al.*, 2014).

As the bolt passes through the intermixing zone between the slow set and fast set resin, the lower region of the fast-set resin will begin to mix first – and this lower region will see the greatest number of mixing revolutions of the fast-set component. As a result, a critical length of fast set resin must solidify first in this same lower region to arrest the bolt rotation, but the upper portion of the fast set component will not see this same level of mixing – hence the inherent risk of un-mixing at the top of the bolt and subsequent variability in load transfer.

Current methods of underground testing

Complications arise when attempting to measure load transfer for spin to stall applications in the underground environment. For traditional resin installations, incorporating a hold time, 300mm Short Embedment Pull Testing (SEPT) is a well-known and commonly used method to determine load transfer. The 300 mm SEPT can utilise a specific mix and hold time to ensure integrity of the resin installation - and then provide a load transfer value over a known 300 mm horizon in the strata. However, for a spin to stall application, 300 mm of encapsulation is too short a length of resin to take the torsional and axial loads that are generated during polymerisation of the resin - a 300 mm resin encapsulation length will be destroyed by these forces and the test bolt will pull from the borehole.

The problem then becomes how to conduct a 300 mm SEPT for a spin to stall installation, given that encapsulation lengths greater than 300 mm are required to arrest rotation and pre-tension the bolt without causing significant resin damage. Previously reported testing methods for spin to stall installations (Altounyan *et al.*, 2003 and Emery *et al.*, 2015) included a split bolt format (SB-SEPT), where the upper 300 mm of the bolt is keyed and pinned and designed to release at low loads during underground pull testing. The top 300 mm of bolt is therefore seen as sacrificial, with plastic cartridge and unmixed resin potentially accumulating in this region. Just below the sacrificial region, the next 300 – 500 mm horizon is then pull tested.

However, it was further reported that the SB-SEPT method was modified to stop bolt rotation immediately after nut breakout (Emery *et al.*, 2015). This means that the torsional loads from nut break out were applied to the resin, but the more significant pre-tension loads were not applied. As a result, the SB-SEPT test method is not a true test of the final installed load transfer associated with a spin to stall bolt, due to the absence of the pre-tension forces during resin polymerisation. The SB-SEPT method also reflects the general assumption that the top 300mm of the bolt is of limited value, presumably due to the effects of unmixed resin and gloving (Aziz *et al.*, 2014). The subsequent risk is inconsistency in load transfer in the top 300mm of the bolt that cannot really be audited.

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KEY PARAMETERS ASSOCIATED WITH SPIN TO STALL

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It is important to fully define the parameters associated with a spin to stall installation, in order to correctly test the repeatability and quality of the bolt installation. While a number of these parameters are shared with traditional resin bolting methods that employ a hold time, there are additional factors that come into consideration for spin to stall applications. It is important that these parameters are properly defined, quantified and measured – the following is a summary of these parameters and their units of measurement.

Physical Geometry

- Borehole Dimensions - Diameter and Length (mm)

- Bolt Dimensions – Diameter, Length and Profile (mm)

- Resin Dimensions – Diameter, Total Length, Dual Speed Component Lengths (mm)

Resin Properties

- Gel times for fast-set and slow-set resin (sec)

- Punch shear strengths for fast-set and slow-set resin (MPa)

Bolt Rotation and Thrust Sequence

- Rotational speed (rpm)

- Rotational time to the back of hole (sec)

- Rotational time at the back of the hole (sec)

- Time to rotational arrest (nut breakout) (sec)

- Cumulative mixing revolutions (mapped per unit resin length) (rev)

- Time to pre-tension (sec)

Installation Loads

- Release torque at nut breakout (Nm)

- Pre-tension axial load (kN)

- Pre-tension torque (Nm)

Installed Resin Quality

- Load Transfer of Installed Bolt (kN/mm)

- Resin Failure Interface (bolt / resin / borehole)

- Bolt encapsulation length (mm)

- Resin mixing effectiveness (% mixed resin, mapped per unit bolt length)

- Gloving (% plastic content, mapped per unit bolt length)

Enhanced surface testing methods

In order to more fully measure the parameters associated with spin to stall applications, enhanced methodologies have been developed to increase the level of test data that is obtained for each installed test bolt. The enhanced test methods are based upon the utilisation of a pre-grouted steel pipe, with a bore hole pre-drilled to accommodate a spin to stall bolt installation, as shown in Figure 3. Instrumentation is incorporated to capture relevant installation data and the pre-grouted steel pipe later permits further test work to be conducted upon each installed bolt.

In preparation for the test, parameters are firstly recorded for the resin type, bolt type and the borehole dimensions - the bolt and resin are then positioned for installation into the grouted and pre-drilled pipe. As the bolt is installed under spin to stall conditions, data capture systems are utilised to record the installation parameters – specifically, the bolt displacement through the resin column and the rotational speed against time – enabling later graphical analysis of the full installation sequence, as shown in Figure 4. This data also provides a record of correct bolt installation, according to specified resin mixing and gel time sequences. The release torque of the nut is known from the shear pin type utilised and the final applied pre-tension is measured using a calibrated hydraulic load cell.

Following completion of the bolt installation, the grouted pipe can now be prepared for laboratory testing. The steel pipe is sectioned as indicated in Figure 5 - and un-needed areas of grout are broken away, producing two 300 mm long specimens for pull testing. The first specimen is from the top 300 mm of the bolt installation, representing the fast-set component of the resin at the top of the bolting horizon. The second 300mm specimen is taken from just below the mid portion of the bolt, representing the slow-set

component of the resin. Each test specimen has an embedment length of 300 mm, in common with SEPT methods utilised underground. Also, during sectioning of the grouted pipe, as the bolt tails are exposed, the resin in these regions can be assessed for quality of mix.
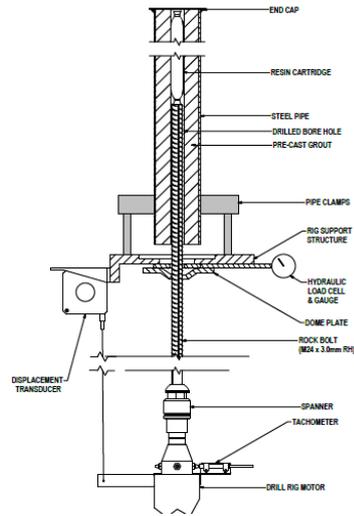

Figure 3: Spin to stall installation rig including instrumentation
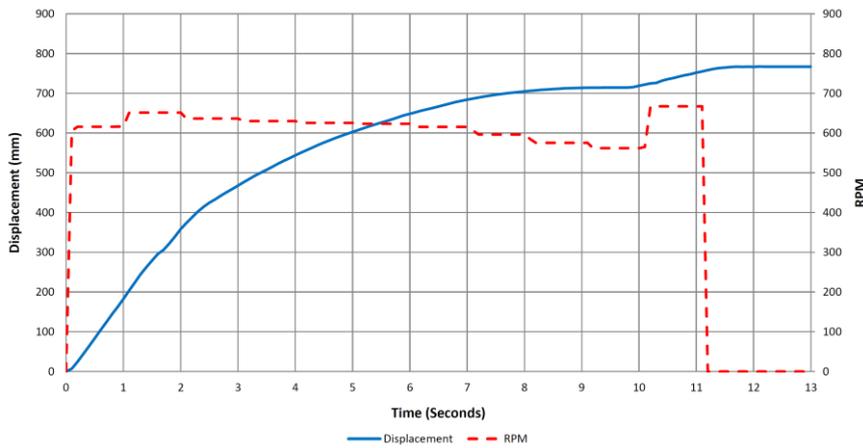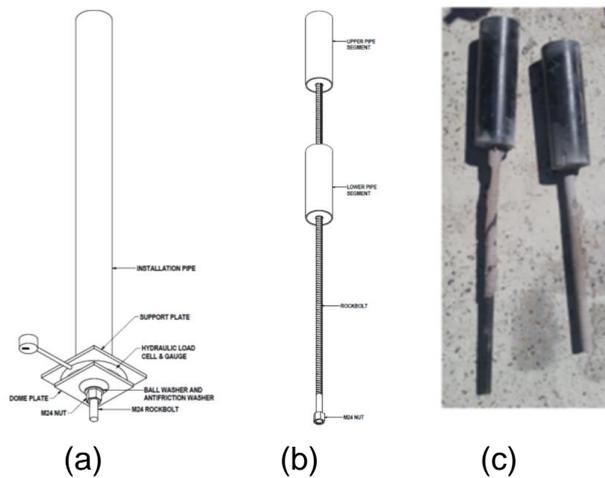

Figure 4: Installation data for a spin to stall test – displacement and rotational speed

(a)   (b)   (c)

Figures 5: Sectioning of pre-grouted pipe containing an installed test bolt

Upon sectioning of the installation pipe, for both pull test specimens, a 'tail' of bolt is kept intact that now permits each test to be conducted as a pull test, rather than a push test. It is known that segmented laboratory push tests can provide contradictory results compared to pull testing methods (Aziz *et al.*, 2006), and this dilemma is now avoided under the new technique. The two 300 mm specimens are then alternately tested under tension in a universal testing machine – measuring both the force and displacement associated with load transfer of the installed resin, as shown in Figure 6a.

Figures 6: Load transfer testing of 300 mm embedment specimens

There are two simultaneous modes utilised to measure and record displacement during the pull test. The first mode of displacement measurement is conducted utilising the cross-heads of the testing machine. This permits measurement of the yield of the steel bar relative to the load transfer that is being generated by the 300 mm sample. The second mode of displacement measurement is conducted with the use of a digital contact indicator positioned on the exposed top of the bolt, as shown in Figures 6b and 6c. This permits direct measurement of the displacement of the embedded bolt through the resin, enabling accurate measurement of load transfer stiffness.

Following completion of the load transfer tests, the two 300mm test specimens can now be further sectioned, as shown in Figure 7, to assess and analyse the resin and bolt interfaces – and whether the resin failure mode has occurred at the bolt surface, the borehole surface or due to shear of the resin. Also, upon visual analysis of the resin interfaces, the percentage of resin mixing effectiveness can be assessed (areas of over mixing and under-mixing), mapped out per unit length along the length of the pull test specimen. The percentage of plastic gloving present can also be assessed, mapped out per unit length along the length of the pull test specimen.

**Figure 7: Sectioning and inspection of 300mm embedment specimens**

This enhanced surface testing methodology provides a comprehensive set of data per test bolt installation. The validation methodology is fully measureable – installation parameters are captured, including the loads applied onto the resin during gel time. Load transfers are measureable via laboratory pull testing in a manner that is more in line with underground SEPT methods. Further to this, analysis of resin failure interfaces, mixing and gloving, are also enabled. Ultimately, the enhanced surface test methodology permits greater ability to bench mark and correlate laboratory based validation data with the bolt installation parameters of underground equipment.

PROPOSED UNDERGROUND TESTING METHODS

As previously discussed, a remaining area of difficulty is that of underground pull testing for spin to stall applications. While the split bolt (SB-SEPT) method provides a relatively low cost and convenient method, there are concerns regarding the incomplete loading of the test bolt during resin gel time, as well as the sacrificial 300mm length at the top of the test bolt representing potential un-mixing of the resin in this region.

An alternate method is proposed for underground validation testing of spin to stall bolting applications, with the intent to capture the correct sequence of installation loads and also provide a true 300 mm SEPT test at the top of the bolting horizon. As shown in Figure 8a, the new method is based upon bolt installation through a pipe and into an upper 300 mm section of the strata which is pre-drilled utilising a standard 28 mm bit. The pipe also has an internal diameter of 28 mm. The lower portion of the borehole is over-drilled to receive the larger outer diameter of the pipe. The pipe also has a torque arm to prevent rotation of the pipe, by way of securing the torque arm to an adjacent installed roof bolt. The pipe can also be coated with a zinc-rich coating to prevent spark generation as the roof bolt passes through, as

well as to slightly roughen the internal diameter of the pipe for resin adherence (Evans 2014). Grease is applied to the upper external surfaces of the pipe to prevent the adherence of any leaking resin between the borehole and the outer pipe wall. While the torque arm can be re-used between tests, the pipe is sacrificial and remains permanently in the ground along with the bolt.

(a)   (b)
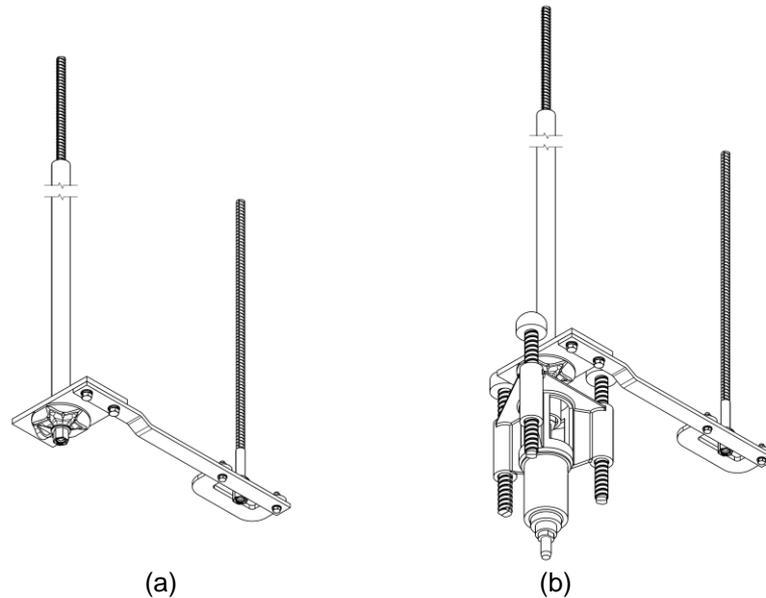
Figures 8: SEPT apparatus for underground validation test work

Once the test equipment is fully prepared, the resin and bolt are positioned for installation under spin to stall conditions. The bolt rotates and is thrust through the resin, with mixing continuing at the back of the hole until gel time and rotational arrest of the bolt. At the point of release of the shear pin, the torsional shear forces are applied through to the internal surface of the pipe, as well as the upper 300 mm of the 28 mm borehole in the strata. The pipe is not able to rotate under these torsional forces due to the constraint of the torque arm.

After break out and advance of the nut, the bolt is now pre-tensioned. The pre-tension forces are applied axially and torsionally through the bolt and resin, and are subsequently constrained by the pipe, the torque arm and the upper 300 mm of the 28 mm borehole in the strata. In this regard, the pipe and upper 300mm borehole have acted in unison to constrain both the torsional and axial loads that are generated during the spin to stall installation.

Preparation is now conducted for the pull test - the torque arm is removed and a tripod pull test chair is placed over the plate with the support legs and pads resting against the strata as shown in Figure 8b. The coupler, pull rod and hollow bore hydraulic jacking cylinder are now positioned onto the chair and prepared for the test. If displacements are to be measured as a part of the pull test, they must be measured with respect to the bolt end and not the jack body, in order to capture bolt displacement and not jack movement. As the jack loads are brought onto the bolt during the pull test, the pipe will not transfer any axial tensile loads as there is no adherence to the strata walls. The axial test loads are now transmitted directly onto the upper 300 mm of the bolt in the strata, providing a true pull test of the upper 300mm bolting horizon.

The pipe method for conducting spin to stall SEPT is no doubt a more complex method and is not proposed for routine daily use. However, the pipe method can be used to provide true underground validation for the load transfer performance of a spin to stall bolt. Upon installation, the full column of resin, and in particular the upper fast-set component, is exposed to the true sequence of torsional and axial loads at gel time. The upper 300 mm of the bolt is installed directly to the strata at the bolting horizon, while the lower part of the bolt is essentially de-bonded from the strata by the pipe. In this way,

the bolt and resin column are installed under true spin to stall loading conditions, but the SEPT is conducted only on the upper 300 mm of the bolt.

CONCLUSIONS

Spin to stall resin installations represent a divergence from traditional resin bolting practices – predominantly due to the immediate sequence of torsional and axial loads that are applied to the resin as polymerisation and hardening occurs. Variations in rotational dwell time, as well as the initiation region of fast-set solidification, can risk under-mixing of resin at the top of the bolt and over-mixing of resin at the bottom of the bolt. Load transfer testing of spin to stall installations is also an area of difficulty, due to the need to replicate the torsional and axial installation loads across the entire bolt length, but to then provide an upper segment for pull testing that is independent from the lower strata.

The enhanced surface testing methods described within this paper permit the replication of spin to stall bolting installations, with the installation parameters being defined and measured. Subsequent load transfer testing utilises laboratory methods that are more in line with traditional underground SEPT methods. An assessment of resin mixing effectiveness and plastic gloving is also incorporated within this test regime. Further to this, underground test methods are proposed that will enable SEPT of spin to stall resins - installed under true loading conditions and pull tested in the upper 300 mm of the bolt horizon.

This review is provided for the purpose of increasing industry awareness of the technical parameters associated with spin to stall resin bolting practices, as well as to identify improvement opportunities in related testing and validation methods. Ultimately, the geotechnical performance of the installed resin bolt is the primary required outcome – and this performance is predominantly a function of effective load transfer from the bolt, across the resin annulus and to the borehole. Effective load transfer remains an essential requirement for all resin bolting practices – and the associated methods of spin to stall validation should be improved to provide a more complete assessment of this critical aspect of strata control.

REFERENCES

Altounyan, P, Bugden, A, O'Connor, D and Berry, R, 2003. Developments in improving the standard of installation and bond strength of full column resin roofbolts, In *Proceedings of the 34th International Conference on Ground Control in Mining,* ICGCM, pp. 263-269,

Aziz, N, Nemcik, J, Craig, P and Hawker, R, 2014. Development of new testing procedure for the assessment of resin performance for improved encapsulated roof bolt installation in coal mines *(ACARP Report C21011)*, Australian Coal Research Limited, Brisbane.

Bigby, D, Kent, L and Hurt, K, 2004. Safe application of mine roadway support systems, *HSE Books*, Norwich.

Canbulat, I, Wilkinson, A, Prohasaka, G, Mnisi, M and Singh, N, 2005. An investigation into the support systems in South African collieries, *Safety in Mines Research Advisory Committee,* South Africa.

Emery, J, Canbulat, I, Craig, P, Naylor, J and Sykes, A, 2015. Development and Implementation of the "Spin to Stall" Resin Bolting System at Anglo American's Australian Underground Coal Operations, In *Proceedings of the 34th International Conference on Ground Control in Mining,* ICGCM, pp. 337-345.

Evans, D, 2014. Next Generation Technology for Corrosion Protection in Ground Support Elements, In *Proceedings of the 14th Coal Operators Conference*, The University of Wollongong, pp. 177-185. http://ro.uow.edu.au/coal/447/

Evans, D, 2015. Improved Roof bolting Methodologies: Reducing Hydraulic Fracture of Strata, In *Proceedings of the 15th Coal Operators Conference*, The University of Wollongong, pp. 129-137. http://ro.uow.edu.au/coal/557/

Hillyer, J, Craig, P, Shuqi, M, Aziz, N, Nemcik, J and Ren, T, 2013. Variation in load transfer along the length of fully encapsulated rock bolts, based on the installation mixing parameters, In *Proceedings of the 13th Coal Operator's Conference*, The University of Wollongong, pp. 137-143. http://ro.uow.edu.au/coal/447/