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2019

# Assessment of key parameters on load transfer during development of a spin-to-stall resin bolt system

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## Publication Details

Kent McTyer, Assessment of key parameters on load transfer during development of a spin-to-stall resin bolt system, in Naj Aziz and Bob Kininmonth (eds.), Proceedings of the 2019 Coal Operators Conference, Mining Engineering, University of Wollongong, 18-20 February 2019, 138-149.

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# ASSESSMENT OF KEY PARAMETERS ON LOAD TRANSFER DURING DEVELOPMENT OF A SPIN-TO-STALL RESIN BOLT SYSTEM

**Kent McTyer**[1]

*ABSTRACT:* Spin-to-stall resin bolting system originated in the late 1990’s at South Africa’s Goedehoop Colliery and has become accepted over recent years in Australian underground coal mines. The main benefit touted is a simplified installation procedure that can lead to both reduced bolting cycle times and more consistent installation quality. These benefits are consistent with mining industry requirements of greater overall efficiencies – especially in mine roadway development rates.

Traditional pre-tensioned resin bolting practice has employed a bolt-rotation stoppage, or hold time, to allow the fast-set resin anchor to fully cure before re-starting rotation to pre-tension the bolt. Spin-to-stall bolting diverges from traditional methods by continuing to apply rotation until the bolt stalls. Continued application of rotation breaks the nut pin allowing the nut to run up the thread to produce pre-tension. While the simplified installation procedure is beneficial, concerns exist over the reduction in resin mixing time – especially at the top of the drill hole. Specifically, whether there is sufficient time for the resin to properly mix and attain full strength. Without full strength the resin anchor at the top of the bolt has reduced ability to transfer load – reducing the resin bolts effective length.

This paper discusses some key resin mixing parameters and their effect on load transfer. These parameters were tested during the development of a spin-to-stall resin bolting system. The test methods simulate underground spin-to-stall installation practice. This assessment technique is thorough and provides industry with greater confidence when evaluating the performance of a spin-to-stall resin bolting system.

## INTRODUCTION

Roof bolting is the dominant primary roof support method used in underground coal mines. They have superior geotechnical applicability and performance in the often-variable strata sequences present in coal mine roofs. Roof bolting is suitable for skin support, suspension of weak or broken roof from more competent strata horizons, beam-building in thick sequences of laminated strata, and for keying of fractured and blocky rock masses (Mark 2000).

The evolution of roof bolting has led to most Australian coal mines using full resin-encapsulated torque-tensioned roof bolts. Bolts employ a fast-setting resin top anchor, a slow-setting resin anchor along the lower length of the bar, and a bottom anchor consisting of the roof plate and tensioned nut. These three elements allow for load from ground movement to be transferred to the steel bar, thereby resisting further ground movement.

Two installation practices, spin-and-hold, and spin-to-stall, are commonly employed. Both involve pushing and rotating the bolt through the resin capsule and spinning the bolt at the top of the drill hole. The more common -- and first-developed spin-and-hold method – employs a bolt rotation hold time of 15 to 20 secs. This permits full hardening of the upper fast-set resin before application of torque-tension via the nut as shown in Figure 1. Adherence to the specified hold time has long been believed to form long polymer chains and, consequently, maximise the

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strength of the upper resin anchor. However, adhering to the correct resin hold time at most mines is human-controlled, and not always possible due to competing production requirements. Failure to adhere to the recommended installation procedure can result in both over- or under-spinning of the resin, or incorrect timing of torque-tension, both of which will reduce the effectiveness of the roof bolt to transfer load. The recognition of the difficulties in achieving consistent installation practice has driven alternative resin-bolt installation practices such as the DSI PEAK System – a single-speed resin system, and spin-to-stall resin bolting.

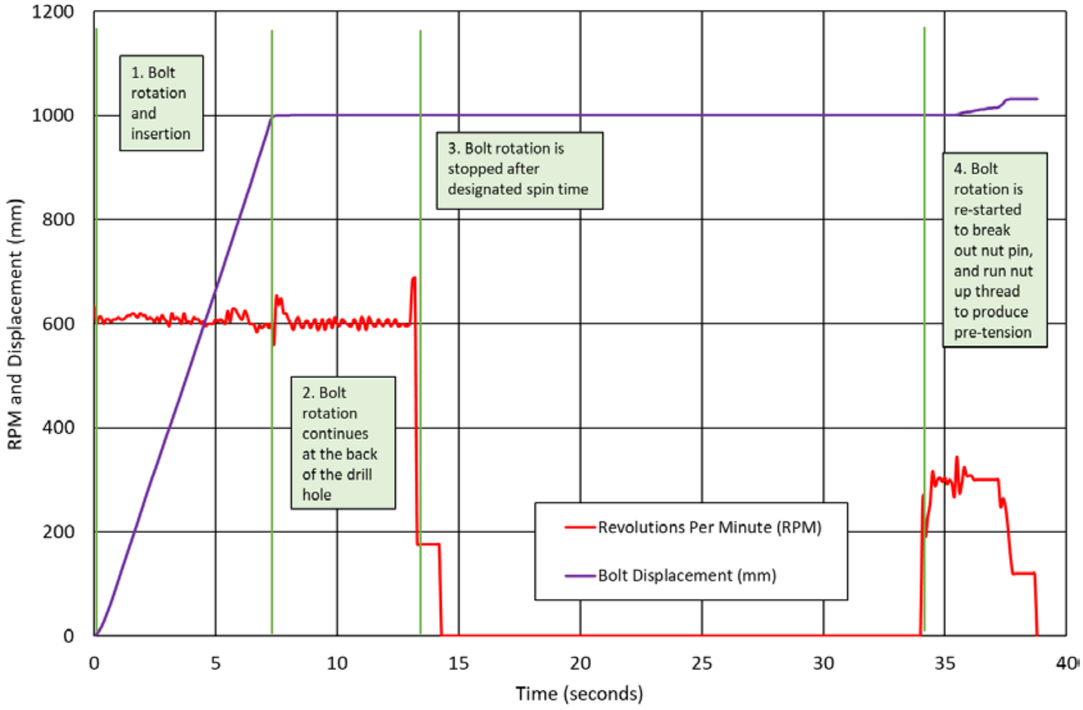


**Figure 1: Drill rig instrumentation showing a typical spin-and-hold resin bolt installation**

Spin-to-stall resin bolting aims to simplify the installation procedure by removing the requirement of a bolt rotation hold-time. The installation practice allows the bolting operator to continue spinning the bolt through the resin until the resin rapidly hardens and binds the bolt, causing it to stall. Continued application of torque, via rotation, shears the pin in the nut. This bolter-delivered rotation then runs the nut up the bolt to develop pre-tension of the bolt as shown in Figure 2. The installation stages of spin-to-stall can also be identified via instrumentation fitted to the drill rig shown in Figure 3.

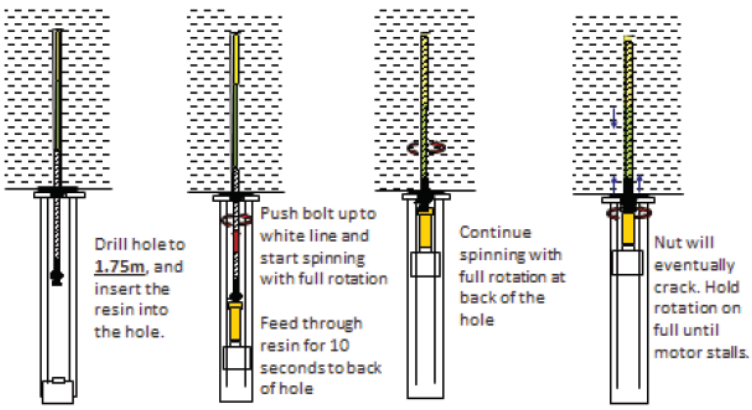


**Figure 2: Spin-to-stall installation procedure (from Emery, *et al* 2015)**

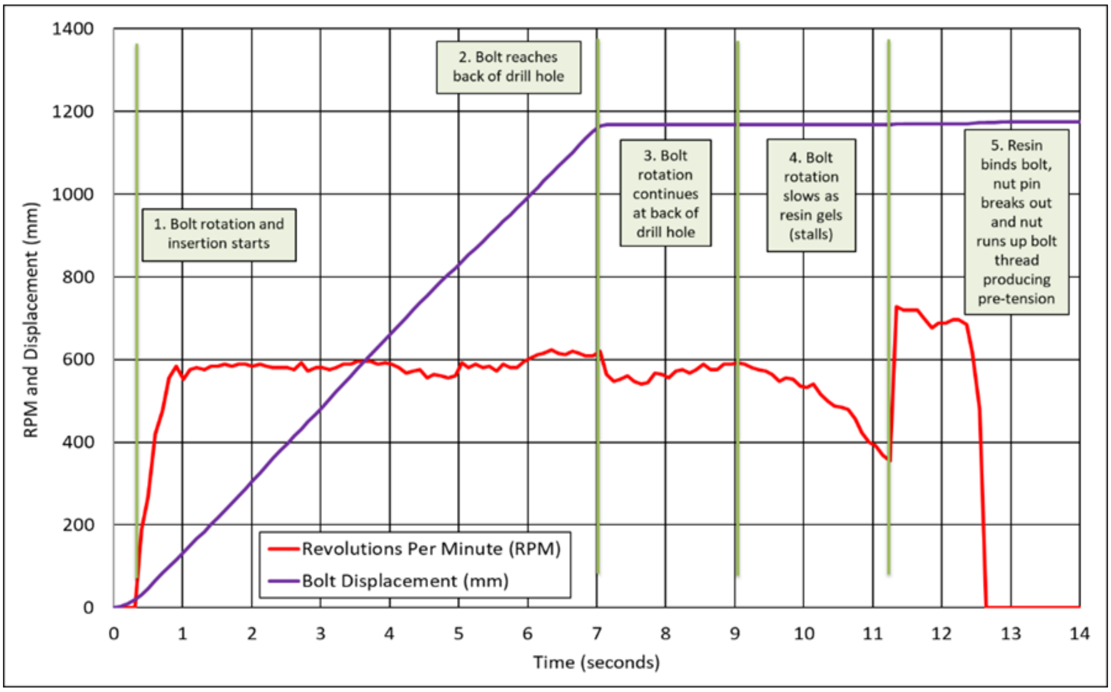


**Figure 3: Drill rig instrumentation showing a typical spin-to-stall resin bolt installation**

Spin-to-stall is a resin bolting system that has been in use since the late 1990s in South African coal mines (Altounyan, *et al.,* 2003). In Australia, the first documented trials were at Grasstree mine in 2011 (Emery, *et al.,* 2015), with increasing market uptake occurring since. Greater acceptance of the spin-to-stall installation procedure has been hindered by both the sensitivity of the system to variation in drill motor torque performance (both across an individual mine and across industry), and uncertainty as to the damage caused by continued rotation of the bolt through the resin polymerisation phase. Another concern is the use of a faster-gelling resin in the top portion of the resin capsule to promote more rapid resin polymerisation and bolt stall. The reduction in resin gel-time also reduces the required mixing time. Note that it is the completeness of the blending of the catalyst and mastic components that uniformly polymerises the resin and ensures it attains full strength.

The primary purpose of this paper is to detail the method and results of a comprehensive validation procedure and discuss some of the lessons learnt during the development of a spin-to-stall resin bolt system. The focus is on two parameters. The first is the influence of pin-nut breakout torque, and the second is the bolt feed rate during installation. Both parameters are systematically varied, with the aim being to increase the resin mixing time when the bolt is at the top of the drill hole. The posited theory being that increasing resin mixing time will result in both higher resin strength and better load transfer performance.

## BOLT INSTALLATION AND TEST TECHNIQUES

The bolt installation and test techniques were developed over several years to evaluate all resin-bolt systems used in soft and hard rock mines and in tunnelling operations. The test procedure was first detailed in Evans (2016). It provides a comprehensive data set for each test bolt. Installation parameters were fully measured using instrumentation on the drill rig illustrated in Figure 3. Load transfer tests simulate underground short embedment pull-testing (SEPT), and the resin-failure interface and resin-anchor defects were evaluated. Overall, the methodology provides a means to both simulate underground spin-to-stall installation practice, and correlate controlled surface and laboratory-based test results with underground test data.

Drilling and installation of resin-anchored bolts was conducted using the DSI coal mine equivalent Sandvik D0100 drill rig shown in Figure 4. Test bolts were anchored into 101.7mm outer diameter, 93.7mm inner diameter steel cylinders with a length of 1800 mm. The steel cylinders were filled with approximately 70 MPa cementitious grout. A 25 mm diameter PVC tube was used to form a pilot hole to ensure the drill hole remained located in the centre of the cylinder. 28 mm diameter semi-spade drill bits were used to drill the hole before resin-bolt installation. The drilled holes simulated underground drilling conditions in a homogenous strata-type.

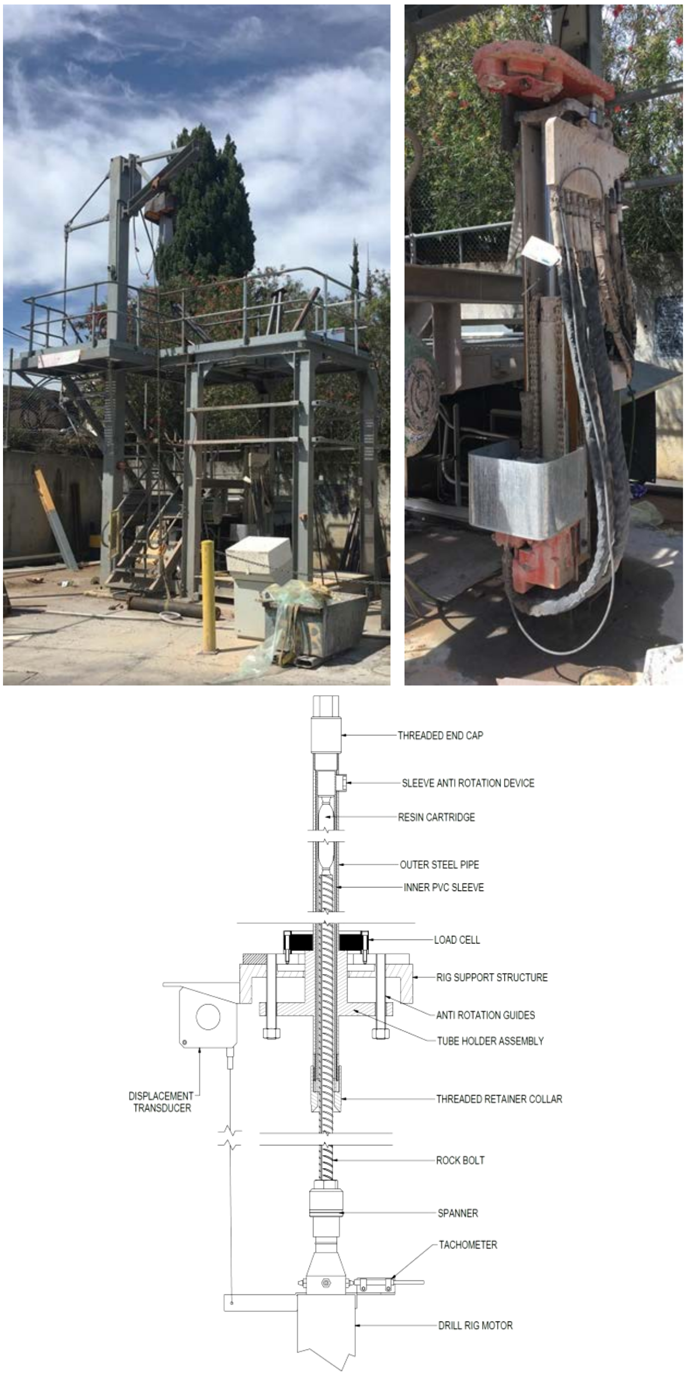


**Figure 4: Drill rig facility at DSI Underground**

Instrumentation during bolt installation recorded bolt travel (displacement) and revolutions per minute (rpm). In addition, a donut-shaped hydraulic load-cell was placed between the roof bolt plate and the drill mast head plate to estimate the retained bolt pre-tension shown in Figure 4. The following consumables were used during testing:

- DSI AXR-profile bar with a nominal core diameter of 21.7 mm and major diameter of 24.7 mm. AXR bar has a typical yield strength of 240 kN, and Ultimate Tensile Strength (UTS) of 340 kN, with 15% elongation (measured after fracture).
- 36AF nuts with high (115-149 Nm) and super high (216-298 Nm) break-out pins.
- 150mm diameter, 5 mm thick star plate, anti-friction washer, and dome ball.
- RocBolt Australia RQ120024STS resin capsules (TORQ). The upper 600 mm of the resin capsule was extra-fast gel-time with the lower 600 mm slow gel-time. Catalyst proportion is approximately 10% of the resin volume.

The three test sample groups are shown in Table 1.

**Table 1: Test sample groups, pin-nut torque and bolt feed rate**

| Test Sample Group Name | Pin-Nut Breakout Torque | Bolt Feed Rate |
|---|---|---|
| **High Breakout, Standard Feed (HB/SF)** | 115-149 Nm | 150mm/sec |
| **Super High Breakout, Standard Feed (SHB/SF)** | 216-298 Nm | 150mm/sec |
| **High Breakout, High Feed (HB/HF)** | 115-149 Nm | 200mm/sec |

Following test completion, two 300 mm-long samples were taken from each complete bolt installation shown in Figure 5. The 300 mm-long samples were taken from all horizons to provide a load transfer profile from 50 mm to 1400 mm from the top of the bolt.

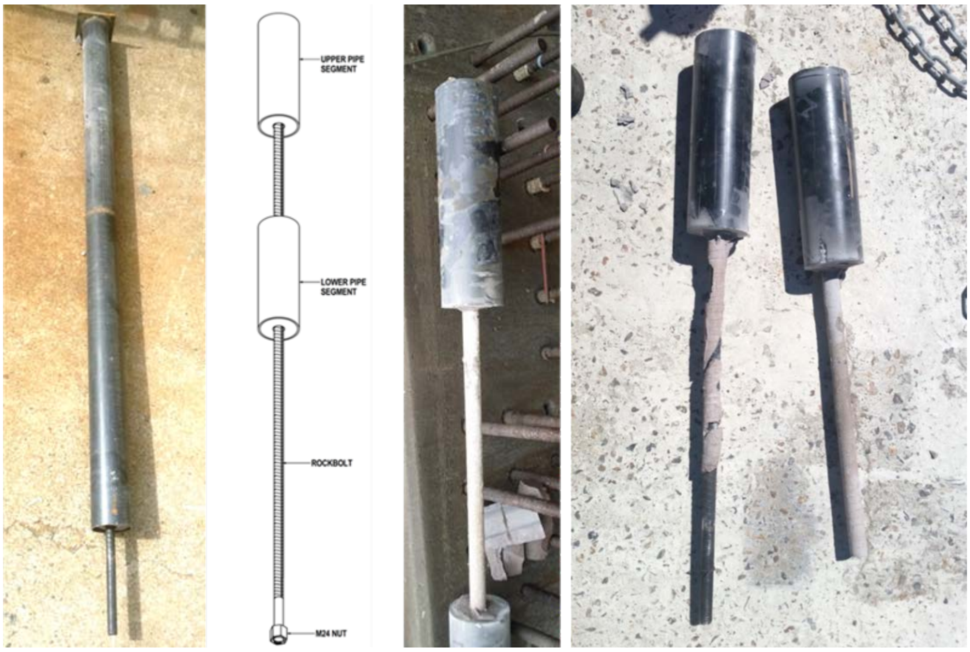


**Figure 5: Spin-to-stall test samples**

The samples were cured for 7 days, then each 300 mm-long sample was pull-tested on the DSI Universal Test Machine (UTM) until either: (a) complete bond failure, or (b) the load attained 300kN. Tests were discontinued after 300 kN to avoid bar breakage. A plunge extensometer was positioned on the top of the sample bolts and pull-tests were video recorded as shown in Figure 6. The plunge extensometer provides a more accurate measure of bolt displacement compared with readings from the UTM cross-head, which contains both take-up of slack in the machine and elongation of the bar (post-yield).


**Figure 6: Pull-test arrangement on Universal Test Machine (UTM)**

Samples were sectioned and inspected after pull-testing. The inspections quantified the proportions of gloving and uncured resin for each 50 mm increment shown in Figure 7. In addition, each observed resin-anchor failure mode was classified as either (a) resin-to-rock, (b) shear within the resin annulus, or (c) resin-to-bolt as shown Figure 7. This resin-anchor failure mode information provides context for the load-transfer results.


**Figure 7: Example observation of resin-anchor defects and mode of resin bond failure**

## TEST RESULTS AND DISCUSSION

Sixty-two bolts were tested during development of the DSI TORQ resin system. Tests compared various combinations of resin components, bolt profile, pin-nut break-out torque, and installation parameters such as feed rate and rotation speed. This report details tests used to refine the spin-to-stall resin bolt system and installation procedure. At this stage the DSI AXR bar profile and resin formulation had been selected based on best and most consistent performance. Thus, the tests discussed in this report examine two parameters: (a) pin-nut breakout, and (b) feed rate. The three test sample groups listed in Table 1 investigate mixing time at the top of the drill hole and how this affects load transfer and resin mixing properties.

### Installation Parameters

Drill rig instrumentation (see Figure 3 as an example) was used to record and calculate average installation parameters for the three test sample groups. Six high breakout standard feed – HB/SF, four super high breakout standard feed – SHB/SF, and four high breakout high feed – HB/HF bolts were installed. Bolts fitted with high breakout pins (HB/SF and HB/HF) spent 3 to 4 sec mixing at the top, while those fitted with the super high breakout pin (SHB/SF) mix the resin for 5-6 sec at the top of the hole. A slight (0.4 sec) increase in mixing time at the top of the hole was found in HB/HF bolts compared with the HB/SF samples. Total installation time decreased from HB/SF (14.1 sec) to HB/HF (13.1 sec). Pre-tension was 10 to 13% lower for the HB/HF sample group compared with the HB/SF and SHB/SF sample groups listed in Table 2.

**Table 2: Installation parameter and pre-tension averages**

| Test Sample Group Name (n) | Time to Top of Drill Hole (sec) | Insertion Rate (mm/sec) | Spin Time at Top of Hole (sec) | Time to Nut Break-out (sec) | Total Installation Time (sec) | Pre-Tension (kN) |
|---|---|---|---|---|---|---|
| **HB/SF (6)** | 8 | 150 | 3.4 | 11.4 | 14.4 | 58 |
| **SHB/SF (4)** | 8 | 150 | 5.5 | 13.5 | 15.5 | 60 |
| **HB/HF (4)** | 6 | 200 | 3.8 | 9.8 | 13.1 | 52 |

### Load Transfer

The three sample groups were tested to compare peak pull-out load shown in Figure 8a. Individual samples were averaged when horizons overlapped. All tests used resin from the same box/batch.

The SHB/SF and HB/HF samples returned a similar load transfer trend over the tested bolt length. The HB/SF samples saw a consistently lower peak load. The returned load is similar for the three sample groups from 850 to 1400 mm from the top of the bolt. This indicates that the slow-setting resin portion of the bolt was less affected by changes to feed rate or total mixing time.

All three test sample groups showed a reduction in peak load transfer from 50 to 350 mm from the top of the bolt. This reduction may be explained by several factors including reduced mixing time at the top of the resin column, and increased concentration of gloving – explained further in a following report section. The 50 to 350 mm region of the bolt showed different resin mixing times for the three sample groups. The results indicate that greater mixing time in SHB/SF and HB/HF tests resulted in higher peak load transfer.

The greatest difference in peak load between sample groups was found from 350 to 850 mm from the top of the drill hole. This segment of the bolt consists of fast-setting resin and is the region believed to be the first to set and cause binding of the bolt. It is also the section of the resin column subject to torsional forces during bolt stall and then axial forces during pre-tensioning. The load transfer results indicate that the HB/SF sample group was more negatively affected. This could be due to bolt stall and tensioning occurring when the resin is in a more critical phase of polymerisation. It is also possible that the SHB/SF and HB/HF samples had already passed this polymerisation phase and are less negatively affected by the bolt stall and tensioning forces.

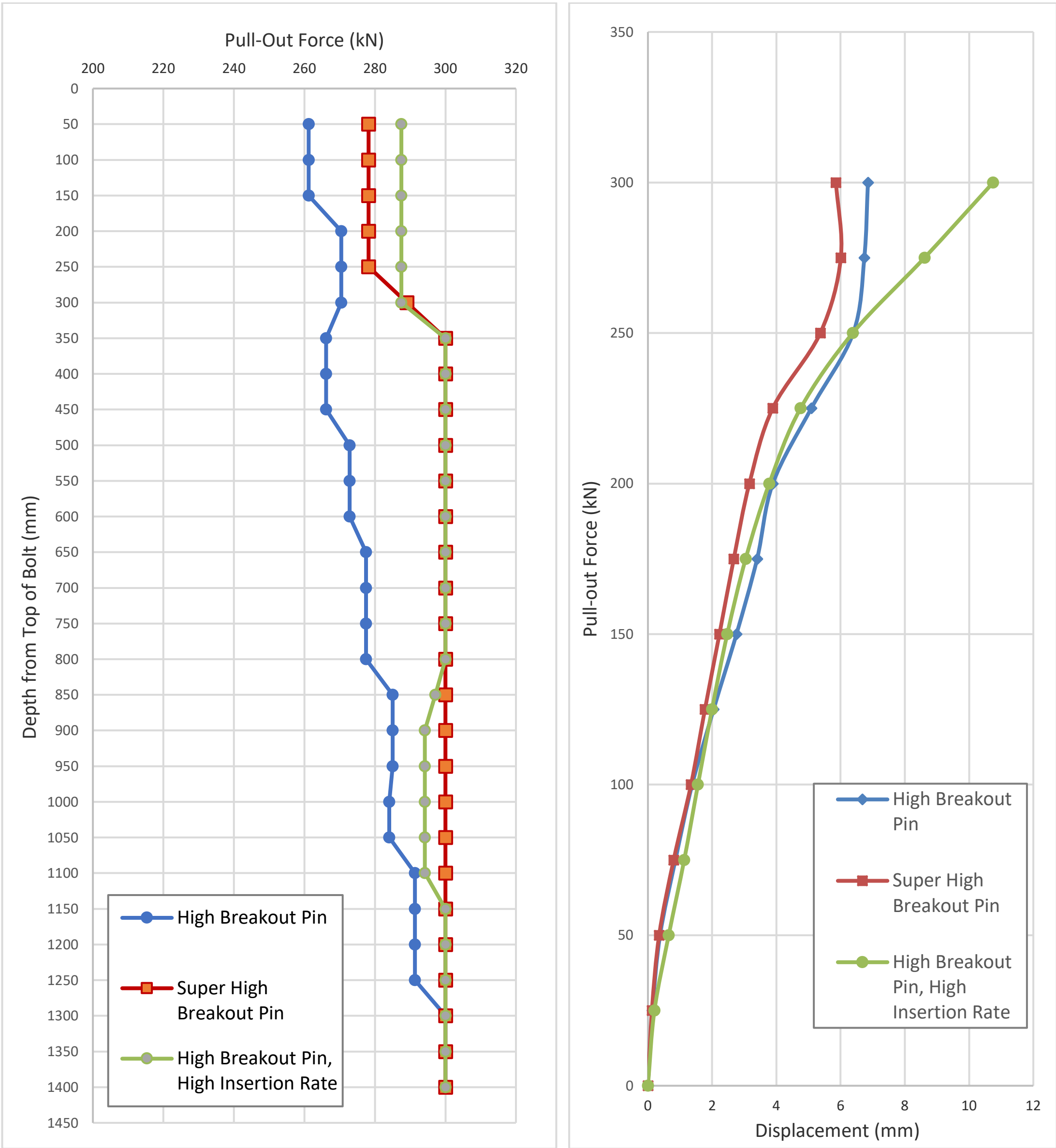


**Figure 8: (a) pull-out force by depth along the bolt (left), and (b) pull-out load and displacement for the three test specifications**

It is generally accepted that the more complete the resin polymerisation, via adequate bolt rotation mixing time, the stronger the resin. The sample groups that had greater average mixing time in the top half of the resin column were the SHB/SF and, to a lesser extent, HB/HF. The results indicate that these two sample groups returned better load transfer. This is believed to be due to more complete mixing of the upper resin column, resulting in stronger resin that is better able to retain integrity and bond strength at the time when torsional and tensile forces occur.

### Bolt and Resin Stiffness

Resin-anchor performance was investigated by measuring both the bolt displacement at the top of the bolt with a plunge extensometer, and the load recorded by the UTM as shown in Figure 6. This method isolates bolt and resin movement through the grout sample, and removes the additional displacement caused by both clamp settlement and bolt elongation, which was recorded by the UTM crosshead displacement. It is therefore a useful method to evaluate the performance of different bolt profiles and resin types. Results of the three test sample groups were averaged at 25kN intervals and plotted in Figure 8b.

As expected, stiffness of the three sample groups were essentially the same because the same resin and bar was used. However, the SHB/SF sample group was consistently stiffer from 50 kN to the limit of the tests at 300 kN. Again, the increased stiffness is believed to be a result of the additional mixing time prior to stall and pin-nut breakout. This produces a more uniformly mixed and polymerised resin with higher strength. Higher resin strength is believed to cause stronger mechanical interlock at the bolt-resin and resin-rock interface, and greater resistance to resin shear in the annulus. Thus, bolt displacement is reduced for a given load.

### Resin Failure Mode

Bolt resin anchors were observed after load testing by removing the steel-encased grout cylinder from the resin-encapsulated bolt. Resin interface failure mode was defined as either: (a) resin to bolt; (b) resin annulus shear; or (c) resin to rock. Each 50mm length was logged, with averages for each of the three test sample groups calculated as shown in Figure 9. Common understanding is that failure at either the bolt-resin, or shear within the resin annulus, will result in higher load transfer than failure at the resin-rock interface. However, this assumes both a strata-type that is significantly weaker than the bolt-resin bond strength, and shear strength of the resin annulus. It also assumes equal resin strength along the bolt length.

The test results show that failure at the resin-rock interface is commonly found where load transfer is high. This finding may be due to both the high load at failure caused by the high grout strength, and the drill hole profile formed by the semi-spade drill bits (which produce minimal rifling of the drill hole wall). Regardless, it is the common occurrence of resin failure in the upper 350mm by both shear of the annulus, and at the bolt resin interface where load transfer is lower, that suggests resin mixing is a key determinant of the mode of resin failure. Again, complete polymerisation of the resin will produce a stronger resin more able to resist the loads occurring during a pull-out test. Conversely, a less polymerised resin will be weaker and therefore more likely to fail both in shear, and at the bolt-resin interface. This incomplete mixing is believed to be the reason for the concentration of resin-bolt and resin-shear failures at the top of bolts where total mixing time is less than lower parts of the bolt. However, it is also noted that weak resin may also fail at the resin-rock interface. This may be the cause of the less-than-conclusive relationship between resin failure mode and load transfer.

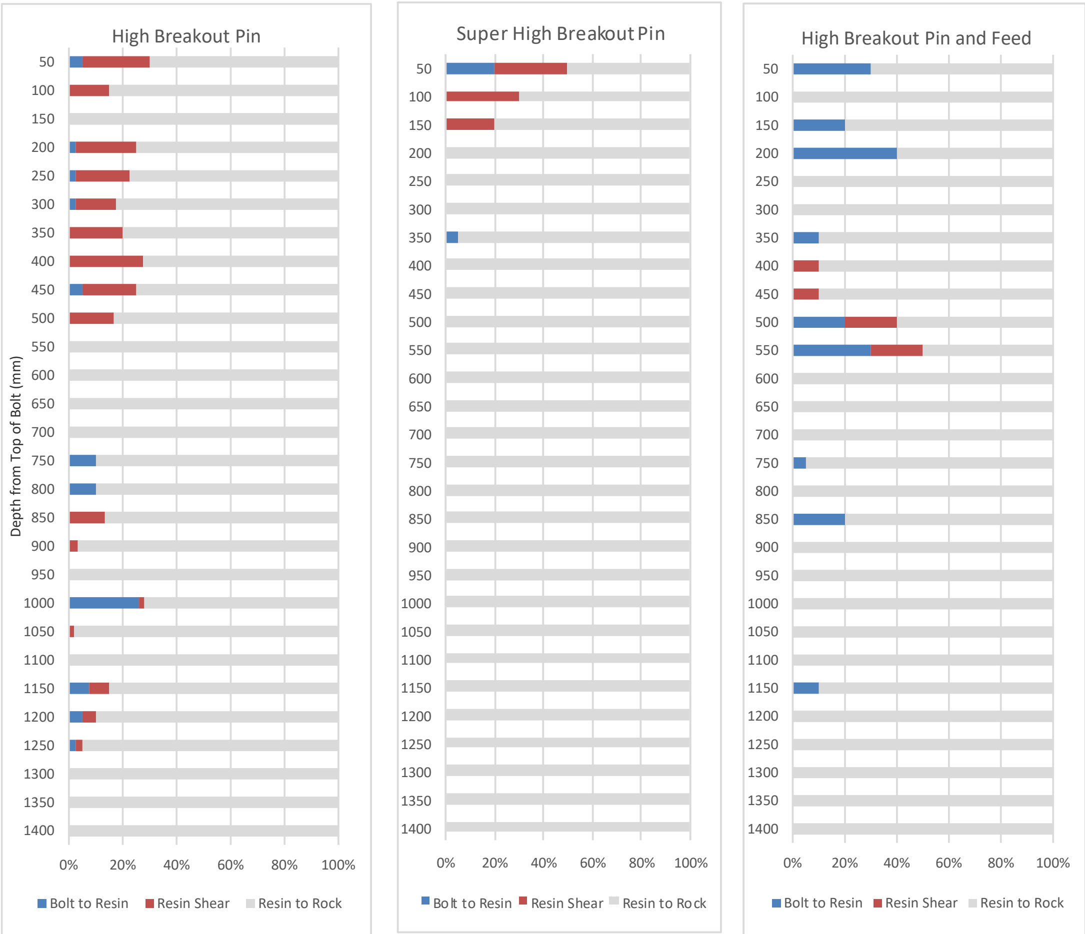


**Figure 9: Resin failure mode by 50mm increment along the bolt**

## Gloving and Uncured Resin

Bolt samples were investigated for the presence of gloving and uncured resin following pull-out load testing. Proportions of gloving and uncured resin were recorded every 50 mm as shown Figure 10a.

Uncured resin was found on one sample from 100-200 mm from the top of the bolt caused by gloving and non-rupture of the catalyst compartment as shown in Figure 10b. To avoid adversely skewing the results this sample was removed from the HB/SF sample group. No other uncured resin was observed. Gloving was pre-dominantly found in the upper 200 mm of each of the three test sample groups. This was expected because the capsule film will tend to wrap and collect around the top of the bolt during insertion to the top of the drill hole. Another concentration of gloving was found in the HB/HF sample group at 500-600 mm. While the cause of this gloving concentration is not understood, it reflects similar findings to McTyer (2015). Low proportions of gloving are also found scattered across the length of the bolts, but was typically only a fraction of the bolt circumference. These low-level gloving proportions are judged to be the background level for bolts installed using resin capsules and, based on the results, are not considered detrimental to load transfer when the underlying resin annulus is fully cured.

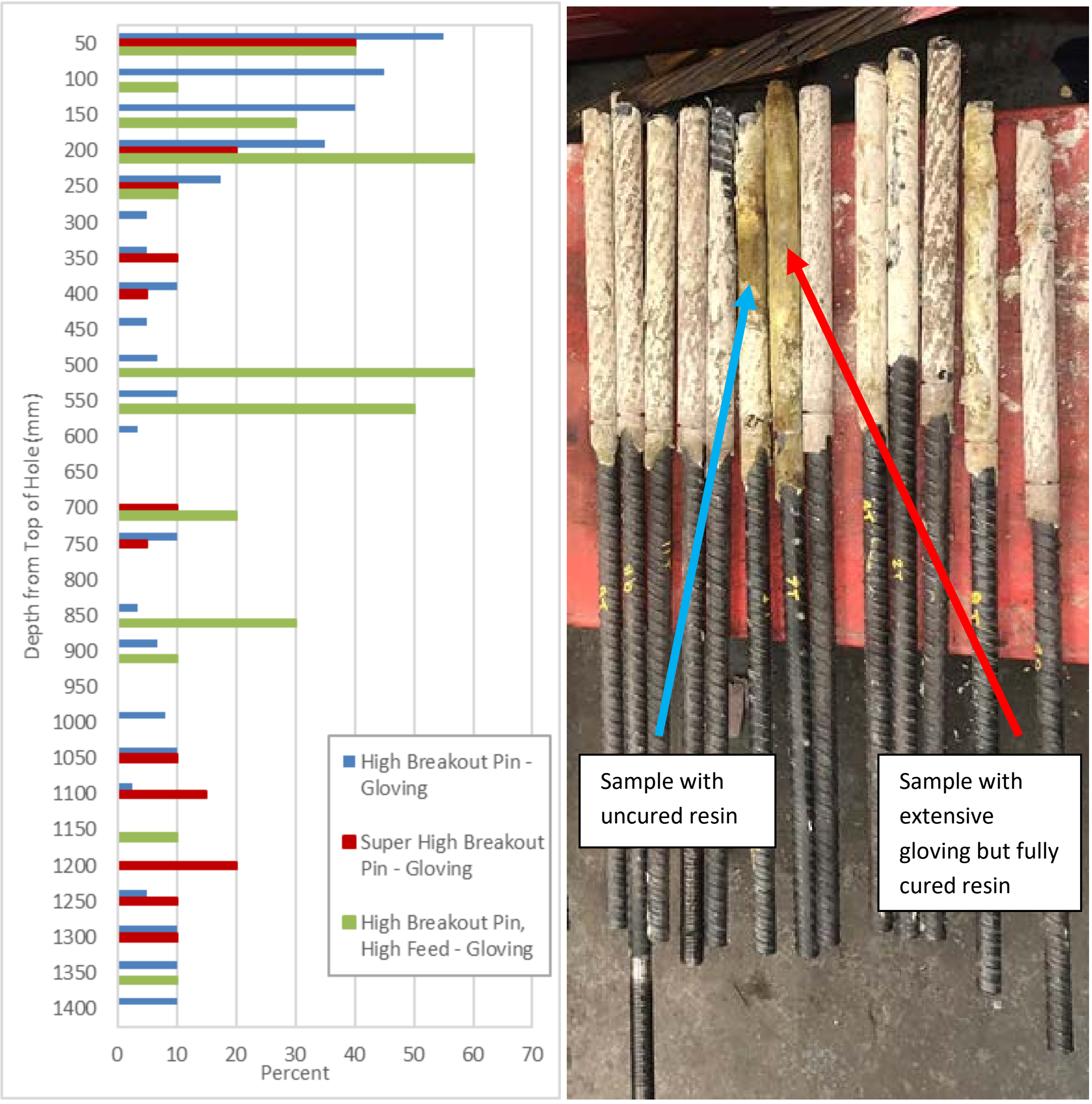


**Figure 10: (a) Proportion of gloving distributed along the bolt length, and (b) sample inspection after pull-out load testing**

## SUMMARY

DSI Underground has developed a systematic methodology for the assessment of resin-anchored bolts commonly used in coal and metal underground mines and tunnelling operations. The method simulates underground installations using drill rig instrumentation, pull-out load testing and observational methods of the resin annulus to comprehensively evaluate each test bolt. Further, the range and number of tests performed on each bolt ensures that any conclusions are supported by multiple evidence sources.

A key conclusion of the spin-to-stall tests is that increasing resin mixing time at the top of the resin column is pivotal to ensuring the best possible load transfer performance of the resin anchor. Traditionally, this has been achieved by spin-and-hold resin that requires a 12 to 14 sec spin time, of which, typically 4 to 6 sec is spent mixing resin at the top of the resin column at the top of the drill hole. However, the change in installation to a spin-to-stall practice involves a faster gelling resin in the top portion of the resin capsule. This promotes more rapid resin gelation and stalling of the bolt. Yet, the reduction in resin gel-time can also reduce mixing time. Noting that it is the completeness of the blending of the catalyst and mastic via bolt rotation that uniformly polymerises the resin, ensuring the resin attains its full strength. Thus, to ensure maximum mixing is achieved before stall, this study changed the installation procedure to evaluate both an increased bolt feed rate, and a change to a higher breakout pin-nut. These modifications attempt to increase the top of drill hole mixing time.

Three test sample groups were evaluated: (a) 115-149 Nm nut breakout pin and 150 mm/sec feed rate – HB/SF, (b) 216-298 Nm nut breakout pin and 150 mm/sec feed rate – SHB/SF, and (c) 115-149 Nm nut breakout pin and 200 mm/sec bolt feed rate – HB/HF. The changes to higher nut breakout torque and feed rate resulted in improvements in load transfer compared with spin-to-stall installations using a 115-149 Nm nut breakout pin and 150mm/sec feed rate. Of the two changes, high bolt feed rates are judged impractical and technically inferior in most coal mine environments where, in the typical weak and laminated strata conditions, the increase in resin pressure could cause resin loss. Further, the total mixing time at the top of the drill hole due to high feed rate is less than when using the higher breakout pin-nut with the normal 150mm/sec feed rate. In addition, the test results by both observational methods and analysis of stiffness, suggest that the resin uniformity and strength was improved when using the higher nut pin breakout with a 150 mm/sec feed rate. For these reasons, the further development of the DSI Underground spin-to-stall resin has proceeded with the super high 216-298 Nm breakout pin-nut.

The results have implications for the ongoing monitoring of spin-to-stall resin bolt systems used in underground mining operations. The link between mixing time at the top of the drill hole and load transfer makes it important for operators and engineers to understand and record this measure during routine spin-to-stall bolt installations. The information can then be used to evaluate the potential load transfer in the critical upper 300-400 mm of the bolt. Should mixing time be found to be inadequate to achieve optimal load transfer then remedies can be explored to optimise bolt performance.

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