ADDRESSING RESIN LOSS AND GLOVING ISSUES AT A MINE WITH COAL ROOF

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ABSTRACT: Over the last year, Jennmar has been supplying roof bolts to a new mine with a thick coal roof in which massive resin loss was being measured. After trying various drill hole diameters, bolt profiles and available viscosities of resin, the mine still did not achieve their designed 90% encapsulation which meant an extra two bolts per metre were being installed. Over-coring to determine where the resin was going revealed that near vertical coal cleat was filling with resin but it also revealed that bolts were gloved for over 50% of their length. Extensive *in situ* testing achieved some interesting new data applicable to that mine site: 1) short encapsulation pull testing of gloved sections of bolt gave similar bond strength to the non-gloved bolts; 2) high viscosity (thick) resin gave improved encapsulation and 3) gloving could only be significantly reduced by a modified bolt end that nearly contacted the side of the bolt hole. Testing methods and results achieved along with comparing them to methods and results from previous literature on roof bolt gloving investigations are reported.

INTRODUCTION

Over the last three years a new longwall mine has been under development in a coal basin that has not been mined by underground methods for over a decade. Routine installation audits of primary roof support within the initial coal seam drivage highlighted significant resin loss (>25%) as a common problem in the thick coal roof. The support rules at the mine stated that the four bolt pattern had to be increased to a six bolt pattern if full encapsulation was not achieved giving the mine a strong incentive to solve the resin loss problem.

Investigations were conducted by Jennmar into the resin loss by over-coring and it was discovered that all bolts were gloved to a significant extent. A project commenced into determining types of improved resin bolting parameters to maximise encapsulation and to reduce gloving.

PREVIOUS RESEARCH INTO RESIN BOLT INSTALLATION AND GLOVING

The following previous research concerning resin loss and gloving were used in developing the methodology for these investigations.

Pettibone (1987)

Resin from three different US manufacturers were installed with the same rock bolt type into concrete blocks. Gloving: "Brand B exhibited glove-fingering in 1 out of 22 tests; Brand C had glove- fingering in 4 out of 24 tests. These incidences of glove-fingering are considered to be minor. On the other hand Brand A had glove-fingering in 22 out of 25 tests". Hydraulic fracture: "Brand A, blocks split in 17 out of 25 tests. About one-third of the blocks split with brand B (7 out of 22). Brand C had no block cracking problems when manufacturer-recommended procedures were followed". The work by Pettibone indicated that the resin properties alone can dramatically alter the extent of gloving and the insertion pressure causing hydraulic fracture of the surrounding rock.

Campbell, Mould and MacGregor (2004)

Extensive testing focussed on reducing the extent of gloving and determining the reduction of load transfer of Australian type rock bolts and resins used in New Zealand mines. Testing of modified bolts gave reductions in gloving with chamfered, wiggled and off-set nut giving the best results.

A strain gauge instrumented bolt installed underground showed near to nil load transfer in the top 400 mm length of the bolt. Laboratory 180 mm long encapsulation pull tests conducted at the University of New South Wales indicated gloving did not significantly reduce the load transfer.

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Pastars and MacGregor (2005)

More extensive pull testing of simulated gloving was conducted by Strata Control Technology (SCT) operations based on the earlier New Zealand experiences. Laboratory pull tests were completed in concrete cylinders using mix and pour PB1 resin as the correctly mixed non-gloved case. Gloving was simulated by using an empty plastic film made to 27 mm diameter inserted into the drill hole and filled with mix and pour resin before adding the bolt. The result was the simulated gloved bolts only providing 10% of the load transfer of the non-gloved test cases. *In situ* pull testing was conducted in coal using the same simulation of gloving with mix and pour resin and an empty plastic capsule. The results were similar to the laboratory test results with simulated gloved bolts only providing 10% of the load transfer of the non-gloved cases.

Compton and Oyler (2005)

US resins and bolts were tested at the NIOSH Safety Research Coal Mine (SRCM). Extensive pull testing was completed using the standard 300 mm Short Encapsulation Pull Test Method (SEPT) versus a new technique of over coring a fully encapsulated bolt to leave 300 mm bonded for pull testing. The overcore method achieved results 35% higher than the SEPT method which was explained by the SEPT having resin loss. The SEPT method used in the US calculates the capsule length required to obtain 300 mm encapsulation rather than reaming the hole and adding excess resin into the top target bond length section as commonly used in Australia. All bolts and US resins over-cored showed some extent of gloving, including off set head bolts. Results from a comparison of six lightly gloved bolts versus four severely gloved bolts pull tested indicated there was no reduction in bond strength from gloving. Installation pressures within the borehole were measured with a result around 34.5 MPa (5 000 psi). Resin loss measured within the SRCM mine roof averaged 44%. It should be noted that typical US made resins are high viscosity in comparison to Australian industry standard resins of 2011.

STUDY OF MINE SITE BOLTING PARAMETERS

Lithology

The typical lithology at the mine site is a thick uniform strong coal roof extending up to 5 m above the normal roof line. Above the coal roof is a thick (>20 m) conglomerate which is sometimes encountered during high drivage for overcasts and belt drive head installations. The test work discussed within the paper was all conducted within the uniform coal roof making up the 1.8 m primary bolting horizon

Bolting machines

Primary support was installed off continuous miner mounted bolting rigs, typically within 2 to 3 m from the face. The bolting rig was hydraulically powered with typical capacity of 1 t thrust and 320 Nm torque.

Primary roof support components

The primary roof bolt used was a 1.8 m long JX profile M24 bolt with typical core diameter of 21.7 mm and rib height of 1.5 mm.

The standard drill bit diameter used was a 27 mm with both spade and twin-wing (angel) profile used. Resin capsules varied due to efforts in solving resin loss. All capsules used were in accordance with the Australian industry standard of 23.6 to 24 mm in diameter.

INVESTIGATIONS INTO RESIN LOSS

Initial underground testing involved encapsulation measurements on the standard bolting variables such as drill bit diameters and resin capsule lengths, along with bolt over-cores to determine where the resin was being lost.
Hole diameters were measured along the length of the drill holes using a borehole micrometer and average diameter calculated. Theoretical encapsulation was calculated assuming no resin loss into the strata. Bolts were installed into the various drill holes using either 1200 mm or 1000 mm long resin capsules and actual encapsulation was measured.

Within the Main Headings c/t 11 test area it was determined that 27 to 28% resin loss was being experienced with 26.5 and 27 mm diameter drill bits. A limited number of tests indicated that using a longer resin capsule could achieve full encapsulation and that using a 28 mm drill bit may also reduce resin loss (Table 1).

Table 1 – Theoretical V's actual encapsulation

	Resin Length	Drill Bit			
		27 mm Spade	27 mm Angel	26.5 mm twin-wing	28 mm twin-wing
Theoretical	1200	2017	1918	2205	1509
Actual		1480	1420	1370	1530
% resin loss		27%	26%	28%	NIL
Theoretical	1400	2353	2238	2572	1761
Actual		1700 + excess	1700 + excess	1700 + excess	1700 + excess

The mine site bolt, drill bit and resin were used for an observed correct installation followed by over-coring to view the sites of resin loss. The bolt was a 1.8 m long M24 JX profile, the capsule was a 1200 mm long, 2:1 mastic: catalyst ratio water based resin, and the drill bit was a 27 mm spade. The installation was 7 s spin from the base of the capsule to the back of the hole, followed by a further 3 s spin at the back of the hole. As shown in Figure 1, the over-cored bolt revealed resin loss into vertical fractures along the borehole wall. Measurements and observations taken on this first bolt showed: 1) gloving with complete intact capsule film was present along the top 650 mm; 2) encapsulation length was 1100 mm which represented 45% resin loss; and 3) no resin was seen in the coal extending above and beyond the drill hole.

Un-mixed yellow fast set mastic was seen migrating from near vertical fractures in the top one third of the empty hole left after the core was removed. A physical sample of this was recovered and confirmed to be resin mastic.

Figure 1 - 1st site over-core: standard bolt, standard viscosity 2:1 water based catalyst resin

A second over-core of a bolt installed some weeks previously as a normal support bolt, being 1.8 m JX with the same standard viscosity 1200 mm 2:1 mastic: water based catalyst was also extensively gloved (Figure 2).

Figure 2 - Overcored bolt taken from the support pattern

Over-coring was completed using an NQ sized rod, as the 75 mm O.D. of the NQ bit was able to fit through the gripper jaws on standard bolting rigs. When over-coring pre-installed support pattern bolts, difficulty was encountered in aligning the NQ sized rod to travel along the 1.8 m roof bolt without hitting the bolt. The over-core method was changed to install a new bolt with the hydraulic rig fixed in position and over-core the bolt immediately. Over-coring to determine resin loss was also targeted within the working face area to avoid any issues with deteriorated roof strata. Over-coring a bolt can be very slow and take up to one hour per bolt. To enable over-coring to be performed off the continuous miner at the development face, an optimum custom made coring bit was found through trial and error with the time improving to below 10 minutes per bolt.

The outcome of the first set of testing was that the mine site increased capsule length to 1400 mm to improve encapsulation.

ADDRESSING GLOVING

Resin capsule film configuration

From visual examination of the gloved bolts, it could be seen that the capsule longitudinal plastic weld had ruptured under pressure allowing the film to open up and lay against the borehole wall. It was decided to perform over-cores on bolts installed using a different type of capsule film configuration. The two types of capsule configurations are shown in Figure 3.

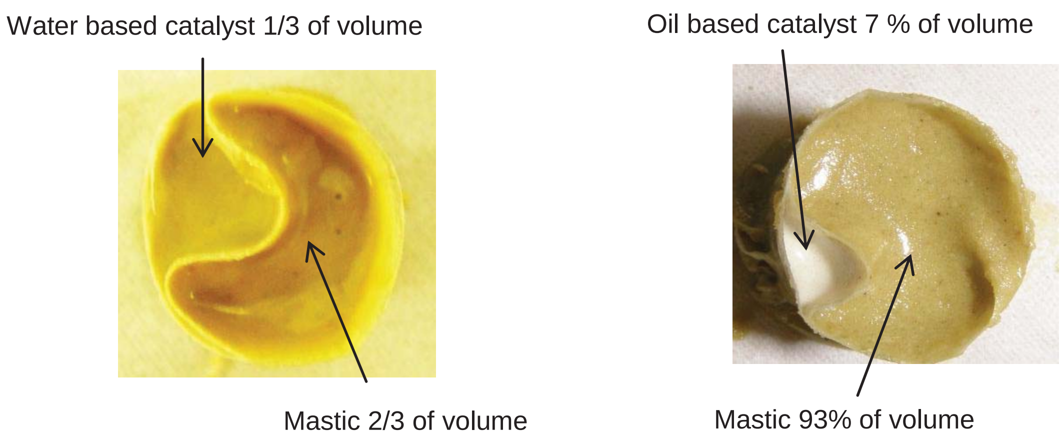


Figure 3 - Cross-sections of the two main types of resins used in the study

Over-coring of three bolts installed with standard viscosity 1400 mm long J-Lok 93:7 mastic: catalyst oil based resin was completed. The over-cores again showed resin loss into vertical fractures within the coal and again showed extensive gloving extending 300 mm to 800 mm in length from the top of all three bolts as shown in Figure 4. The two capsule film configurations did not appear to vary the degree of gloving and both appeared to have opened up along the plastic weld and lay against the borehole wall in a similar manner.

Figure 4 - Three over-cored bolts, 93:7 ratio mastic: catalyst oil based, standard viscosity

Modified bolt end

A modified bolt end was manufactured similar to those shown in Figure 5 with the intention of the point contact and the flat edges shredding the plastic film. A 1400 mm long high viscosity (thicker) J-Lok 93:7

oil based resin was also used in view of creating more turbulence for film shredding. The high viscosity resin was tested alongside the standard viscosity 1400 mm long 2:1 ratio water based resin. Eight "pinched ear" bolts were installed and encapsulation measured with two bolts removed by over-core.

The five bolts installed with the high viscosity J-Lok all had excess resin expel from the holes during installation, while the three installed with standard viscosity 2:1 water based resins measured 300, 380 and 900 mm free length from the collar. Surprisingly the thicker high viscosity resulted in less resin loss.

Figure 5 - Pinched ear bolt modifications

Both 26 mm wide pinched ear bolts over-cored were less gloved than previous standard bolts with the plastic film broken into segments. The higher viscosity resin combined with the pinched ears bolt was even less gloved (Figure 6).

Figure 6 - Overcores using a single 26 mm wide "pinched ear" bolt

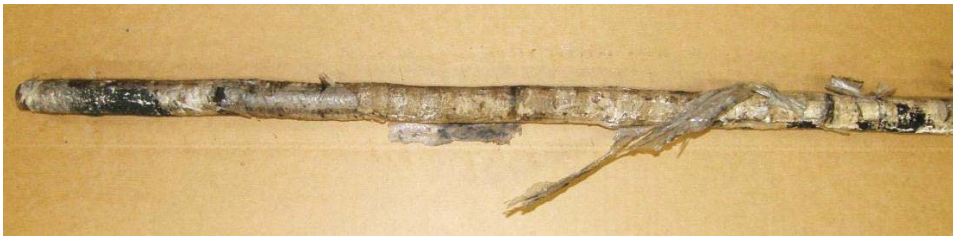
After considering the gloving improvement and ease of installing the 26 mm pinched ear bolts, various widths and number of pinched ears were then tested. It was determined that a single 28 mm wide pinched ear could be installed into a hole drilled with a 27 mm drill bit. It should be noted that previous measurements of hole diameter in coal with a 27 mm bit were 28.1 to 28.5 mm in diameter.

Over-cores of larger 28 mm wide pinched ears and standard bolts were conducted with two different types of know resin viscosities (Figure 7).

Further bolt installations were performed for measuring encapsulation in the same area. Single pinched ear bolts, 1 400 mm long capsules, with standard viscosity 2:1 ratio water based resin loss between 37% and 40%. A standard 1.8 m bolt gave 47% resin loss with the same resin. However, six standard 1.8 m bolts installed with the J-Lok high viscosity (thicker) resin of various capsule lengths gave nil resin loss.

A two hundred bolt trial was attempted of the single "pinched ear" bolts with a high viscosity water based resin. It proved difficult to consistently get the bolts to the back of the hole with the 1 t standard thrust of the bolting rigs with many nut shear-pins breaking out prematurely.

After the failed bulk installation trial, further testing was conducted over four separate days to determine the importance of continuing the project towards eliminating gloving and to further investigate encapsulation gains with high viscosity resin.



(a) 1 x 28 mm Pinched Ear, site 2:1 water based resin - extensive gloving with plastic film intact along 900 mm of bolt

(b) Standard bolt, site 2:1 water based resin - extensive gloving with plastic film intact along 600 mm of bolt

(c) 1 x 28 mm Pinched Ear, JLOK High Viscosity (thick) resin. Well shredded plastic film only 5 - 10 mm in size, well mixed entire along the entire length and colour indicating contact to the coal strata along the entire length.

Figure 7 - Various overcores showing the thicker resin also reduced gloving

Load transfer testing of gloved bolts

A limited number of over-core pull tests were able to be performed using the test methodology described by Compton and Oyler (2005). The method requires a bolting rig to be set in position for up to three hours without moving. A continuous miner with bolting rigs was used at the face during a maintenance shift and one test was done on each side of the miner without moving. The testing method as illustrated in Figure 8 shows the bolt being removed after pull testing to determine the extent of gloving.

The results of the gloved bolt pull tests were compared to some simple Short Encapsulation Pull Tests (SEPT) completed without any reaming but using a short capsule targeting 300 mm encapsulation. The SEPT bolts were not over-cored, due to time constraints, but were assumed to be not gloved. This assumption was based upon the section of all other bolts viewed not being gloved within the bottom 500 mm of initial mixing through the resin capsule and the capsules used for SEPT were less than 200 mm long.

The results for the SEPT testing were 12 to 15 t and assumed to be the no gloving scenario. The over-core pull tests of gloved bolts achieved 12 to 13 t. The testing was quite limited but the results indicate no major difference in bond strength between the two sets of tests.

Removal of the first pull tested bolt by over-core showed damaged to the resin by the core bit hitting the side of the bolt within the top section (Figure 9a) but extensive gloving was present. It was decided to remove the other bolt by continuing to pull it out using the pull test ram. The second bolt was also gloved within the top half of bolt and interestingly indicated failure mode of the resin bond (Figure 9b). The resin appeared to have been crushed under mostly compression for the top 200 mm with the bottom 100 mm being mostly shear failure along the contact with the borehole wall. This is only an indication as some damage would be expected during the bolt pull out even at less than the 12 t loads in the coal roof.

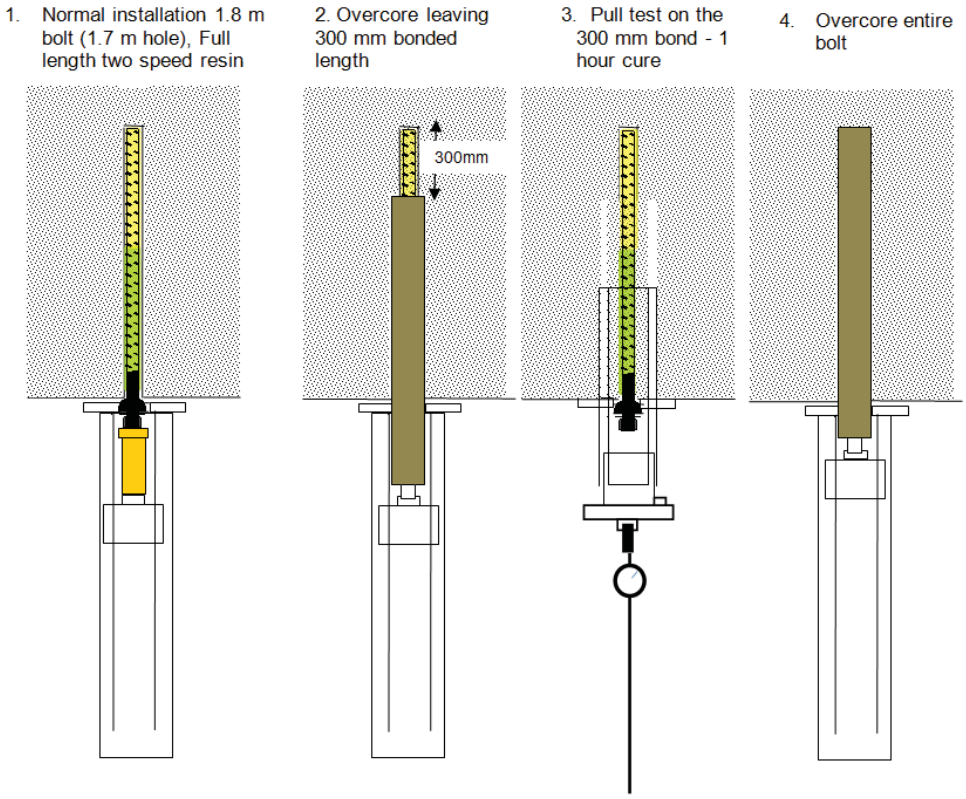
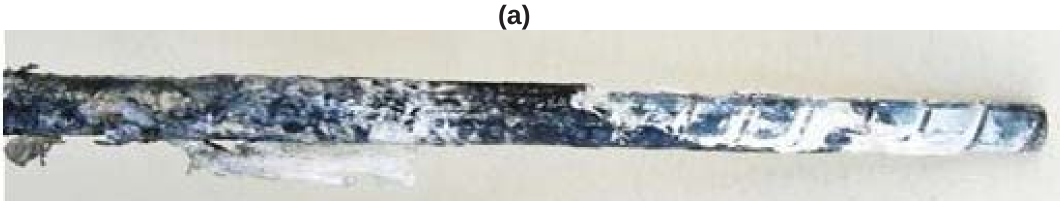


Figure 8 - Overcore pull test method

(a)



(b)

Figure 9 - Bolts removed after pull tested using the overcore method

ADDRESSING ENCAPSULATION

Considerable effort had been expended into investigating and attempting to solve the problem of gloving. It was accepted by the mine management that the *in situ* pull test results combined with literature reviewed, indicated gloving is not detrimental to bolt/resin and rock bond strength as it was first considered. The mine management's main concern was the issue of poor encapsulation; Resin loss was being measured at 40 to 45 % with the standard viscosity resin and the change to 1400 mm long capsules did not achieve full encapsulation. Various trials conducted by the mine on lower viscosity resin and smaller rib deformations on roof bolts did not produce improvements to encapsulation. Back analysis of testing conducted with high viscosity J-Lok resin aimed at reducing gloving indicated that the thicker resin gave a much improved encapsulation (Figure 10).

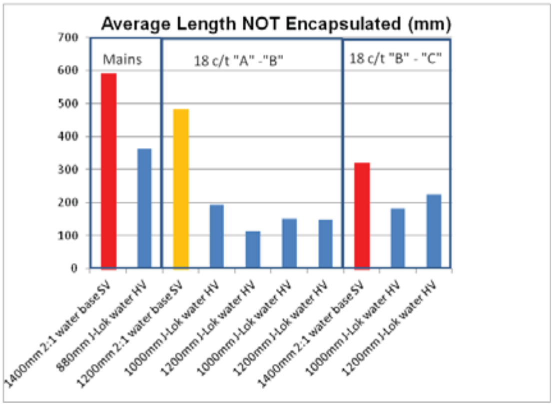


Figure 10 - Encapsulation Comparisons Standard Viscosity (SV) V's High Viscosity (HV)

A bulk installation trial was conducted four months later in the colder months of June using 1200 mm long high viscosity water based J-Lok resin in the mains headings. The thicker resin was found to be noticeably more difficult to force the bolts to the back of the hole without the shear-pin breaking in the nut, but generally they were successful. Encapsulation targets were met with over 85% of bolts having resin appear at the collar and the length not encapsulated on the other 15% of bolts ranging from 100 to 350 mm. A further installation trial was conducted in a gateroad development panel some two months later. The same high viscosity water based resin was successful but a coarser limestone high viscosity oil based resin was also trialled and proved successful with an improved ease of bolt insertion without shear-pins breaking out in the nuts.

A full implementation commenced through-out the mine site using the new 1200 mm long J-Lok coarse limestone high viscosity oil based resin. Encapsulation measurements were conducted within the same 100 m of roadway of the new resin versus the previous mine site standard viscosity 1400 mm long resins. The result was that the new J-Lok resin achieved an average improvement of 200 mm encapsulation with a 200 mm shorter capsule. To date, all measurements with the new resin have had the length not encapsulated measured to the collar being less than 300 mm.

CONCLUSIONS

The high standards set by a new mine site in regards to ground support and pursuing full encapsulation of rock bolts has led to a considerable investigation into resin bolting within the very thick relatively uniform coal roof.

The over-coring of rock bolts highlighted a problem with resin loss into fractured rock about the bore hole, but more concerning in the initial stages was the extensive gloving on the bolts. During testing of various modified bolt end profiles it was determined that "pinched ear" ends of 26 to 28 mm widths (patent pending) installed into a hole drilled with a 27 mm bit can significantly reduce gloving, but installation difficulties using standard Australian bolting rigs would need to be overcome. It was found during the same tests that higher viscosity resins definitely reduce resin loss within this mine site roof type in comparison to previous Australian industry standard resin's viscosity.

Load transfer testing using the overcore pull test method was successfully completed within the mine roof at the development face. The results from the significantly gloved standard bolts was similar to the assumed "non-gloved" SEPT and importantly was typical for strong coal roof at 12 to 13 t per 300 mm encapsulated. The concern for bolt installation changed back from gloving to again focus on improving encapsulation.

A new J-Lok high viscosity coarse limestone oil based catalyst 93:7 resin has been successfully implemented at the mine site. The results to date have given an improvement of 200 mm to encapsulation length with a reduction of capsule length by 200 mm. The length of bolt not encapsulated from the collar is now consistently below 300 mm.

ACKNOWLEDGEMENTS

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