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# ***IN-SITU* PULL TESTING OF CABLE BOLTS ENCAPSULATED WITH INJECTION POLYURETHANE**

**Peter Craig<sup>1</sup> and Brett Murnane<sup>2</sup>**

**ABSTRACT:** Polyurethane (PUR) injection into underground coal mine strata has been practiced in Australia as early as 1985. The ACARP report C100019 discussed several case studies of which one included PUR injection into resin anchored, pre-tensioned hollow central tube cable bolts.

In cases of rapid response to accelerating strata movement it is the preference of site geotechnical personnel to install immediate pre-tensioned cable support, followed by re-consolidation of the strata through injection of grout or PUR. Cementitious grouting of cable bolts has two operational time restrictions; 1) 24-48 h restrictions can be placed on roadway widening or longwall chock removal while waiting for the grout to achieve adequate strength and 2) a 24 h restriction being placed on PUR injection after grouting has taken place to avoid unwanted chemical reactions and heat generation. In the last few years, more mines, faced with time critical ground support, have been utilising hollow cable bolts as the support and the means of injecting PUR into the strata. The main reason is time, 24 h lost to cementitious grout curing could be used in stabilising the strata by PUR injection into distant fractures, and operationally 24 h gained on a longwall move represents a large financial advantage. It has been considered that foregoing cementitious grouting of cables and replacing it with PUR will reduce the load transfer of the cable bolt, but no readily available data exists on how much reduction in bond strength occurs. Underground short encapsulation cable pull tests were conducted at Springvale Colliery comparing cementitious grout against PUR at both 24 h and nine days cure time.

## **INTRODUCTION**

The application of polyurethane (PUR) injection is usually considered as a last resort for Australian coal mines due to the high cost and chemical hazards involved. PUR injection is typically used where control of the roof has been lost or it is considered it soon will be. The injection of PUR in situations, where the roof of a roadway has undergone considerable displacement/deformation and is highly fractured, has frequently resulted in successful outcomes (Buddery, 2003).

Injection of PUR into seven 7 wire cable bolts is increasingly practiced in US coal mines to provide corrosion protection, control of strata groundwater ingress and additional roof stabilisation (Faulkner 2012). It is possible to inject PUR up through the 1- 4 mm gaps of a cable bolt housing and wedge, whereas cementitious grout requires cables with a more significant opening over 10-12 mm diameter for pumping. Whereas the US coal mines typically use point anchored seven wire cables up to 36 t Ultimate Tensile Strength (UTS), Australia predominantly uses pre-tensioned, post grouted (cementitious) hollow strand cables typically 60 t UTS. The larger 10-12 mm diameter central injection tube of Australian hollow cable bolts allows pumping of either PUR or cementitious grout with little modification to standard equipment.

Research into the geotechnical aspects of Longwall recovery in Australian coal mines recommends that mines with weak roof should employ systematic cabling. Cable bolts should be at least 6 m in length, anchored outside the likely roof failure zone and be grouted at least 24 h prior to commencement of chock removal (Hill, 2010). Cementitious grouting of cable bolts poses two operational time restrictions; 1) 24-48 h restrictions can be placed on roadway widening or longwall chock removal while waiting for the grout to achieve adequate strength and 2) a 24 h restriction is placed on PUR injection after grouting has taken. In more recent years at least three Australian mines used PUR for repeated Longwall recovery ground support due to problems experienced with previous recoveries and known geological issues. Operational reasons have led to the adoption of PUR injection through the 6-8 m long cable bolts to replace separate cementitious grouting of cable bolts and PUR strata injection.

Throughout December 2011, Springvale Colliery's Longwall 414 recovery experienced a small roof fall and significant chock convergence, extending the time from reaching zero chainage to last chock

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recovered out to eight weeks. During that period PUR was injected on several occasions into the strata and successfully into cable bolts, which had failed to grout. In February 2012, after back analysis of events a test plan was developed with Jenmar to determine the bond strength of cable bolts injected with PUR.

## UNDERGROUND TEST PLAN

### Departmental approval

An application was made to the NSW Department of Primary Industries under Clause 49 of the Coal Mines Health and Safety Regulation 2006, to conduct a "High Risk Activity" in the application of polymeric material for strata control. The application, outlining the reasoning for the testing of bond strength of PUR with cable bolts, was approved for the location 416 panel, 1 C/T, a slant drivage indicated in the shaded area of Figure 1.

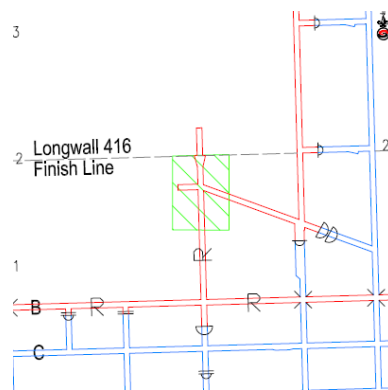


Figure 1 - Test area 416 panel

### Pull test plan

Recent laboratory testing of fourteen different types of Australian cable bolts in sandstone (UCS of 19-25 MPa) identified that bulbed or nutcaged cables can have up to 400% higher load transfer capacity compared to plain-strand cables (Thomas, 2012). Considering the different modes of anchorage for plain and bulbed cables, it was necessary to test both types with PUR alongside grout for a comparison. The cables selected were; 1) Plain 28 mm hollow strand and 2) Bulbed 28 mm hollow strand. The plain strand is a nine wire 28 mm diameter cable with 63 t capacity, it has a 12 mm diameter central hollow tube for post-grouting. The bulbed strand is made from the same 28 mm diameter hollow strand but with 1 x 35 mm diameter non-collapsible bulb (nutcage) located in the middle of the 400 mm long pull test section. Both types of cable were installed into a hole drilled with 45 mm diameter twin-wing bits to suit Springvale mine drilling conditions through clay roof, the two types of cable are designed for use with 42 mm drill bits for the majority of mining conditions. The 28 mm hollow strand has had over one thousand cable bolt installations on Longwall recovery roadways as 6-8m cables and PUR injected. The contractors pumping the 1.8 m long pull test specimens were familiar with the PUR injection of the full scale 6-8 m product and they injected the test cables using the same method.

The test cables were separated into two locations, the PUR cables in the slant roadway and the cementitious grouted cables 50 m away in a stub. The separation of the cables into two locations enabled PUR injection and cementitious grouting on the same shift and inspection of the strata indicated the two sites were similar. This enabled the pull testing at 24 h to be completed on both sets of cables on time.

The typical roof lithology at Springvale Colliery is a 3-4 m thick predominantly coal roof with two 100-200 mm thick claystone bands located within the bottom 1.2 m horizon. The pull test cable bond length was selected at the 1.3-1.7 m horizon to: a) avoid the dominant claystone bands; b) extend beyond immediate roof features and fractures; and 3) minimise the length of free cable to reduce strand rotation during pull testing. A roof core was taken during test cable installation in the area of the cementitious grouted cables; the stratigraphy referenced to the de-bonded test cables is shown in Figure 2. On the day of installation of the test specimens, the final bond length location was predominantly in coal but two thin claystone bands of 25-50 mm thick were present. Grout cube samples from the batch pumped into the test

specimens were collected for laboratory testing. The quality control for the PUR pumping was measurement of volume and pressure into each cable.

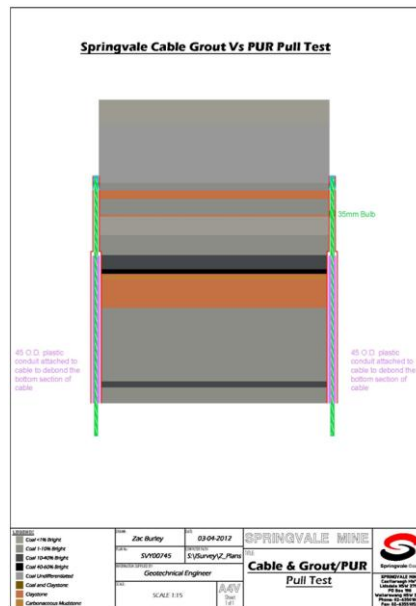


Figure 2 - Stratigraphy from core log referenced to test cables

## RESULTS AND DISCUSSIONS

### Grout and PUR properties

The top-down pumped high strength thixotropic grout was mixed at an approximate Water: Cement ratio (W/C) = 0.35 (5.25 litres per 15 kg bag). Typical Uniaxial Compressive Strengths (UCS) for the product at this water: cement ratio were 30 MPa at 1 d, 55 MPa at 7 d and 70 MPa at 28 d. The 50 mm cube samples taken underground from the mixture during test specimen grouting were tested at seven days to give a UCS values of between 45-49 MPa.

Nine test cables were pumped with Marithan N PUR in the same top-down manner as the grout, with pumping at a very steady pace to allow foaming to start and seal the bottom section before filling and pressurising the top bonded pull test section. Three cables failed due to excessive leakage of the packing material at the collar of the hole and subsequently failed the pull testing. The successful test cables took approximately 10 L of PUR each, which equates to a void fill of approximately 20 L considering the Marithan N used has an expansion factor of two. The theoretical volume of void around the 28 mm diameter test cables equated to 17 L. The pump pressures recorded to reach the 10 L of PUR was typically 40 bar, with four cables taking 100 bar which was most likely due to the foaming starting within the cable hollow tube before completion of the hole. The specification data sheet for Marithan N PUR is a laboratory compressive strength of 10 MPa and bonding strength to rock/concrete of 1 MPa.

### Load displacement results (400 mm bond length)

The equipment used for 24 h pull testing was a 30 t cable bolt tensioner of known ram area for conversion to metric tonnes. The displacement of the cable relative to the mine floor was measured from the cable tail protruding below the tensioner against a convergence pole fitted with mechanical dial gauge accurate to 0.1 mm. After the Bulbed 28 mm Hollow Strand unexpectedly reached the 30 t capacity of the tensioner used at 24 h testing without peak load being achieved, the nine day tests included a 60 t hydraulic cylinder over a stem connected to a threaded barrel and wedge. The displacement measurements taken using the 60 t pull test cylinder were taken from the bottom of the protruding threaded stem. The displacement readings measured off the threaded stem were corrected for normal barrel draw over the wedges under load.

The foaming reaction of Marithan N PUR commences within 1-2 min and is completed within 3 min. The fast reaction of PUR has it achieving 90% of its strength within the first two hours (Buddery, 2003). The original plan was to include three bulbed cables with PUR at 24 h and three at nine day to confirm the

strength over a reasonable time frame applicable to longwall recovery. Due to the three leaking failures during installation, only three bulbed test cables remained viable so one was completed at 24 h with the remaining two at nine day.

The load versus bond displacements graphs were produced for each test cable as shown in Figures 3, 4 and 5. The peak load behaviour of both plain and bulbed strands in grout was a sudden release of load with a loud pop before reloading. The nature of the mechanical dial gauge setup jolted by the sudden movement prevented accurate reading of displacement after peak load was reached. This failure mode is likely related to the coal roof and is seen with rock bolts in coal roof and not in stronger rocks. It suggests the failure interface could be the coal or coal/grout interface. The PUR injected cables exhibited similar initial stiffness to the grouted cables but reached much lower peak loads and rapidly lost load but not in the sudden manner of the grouted cables.

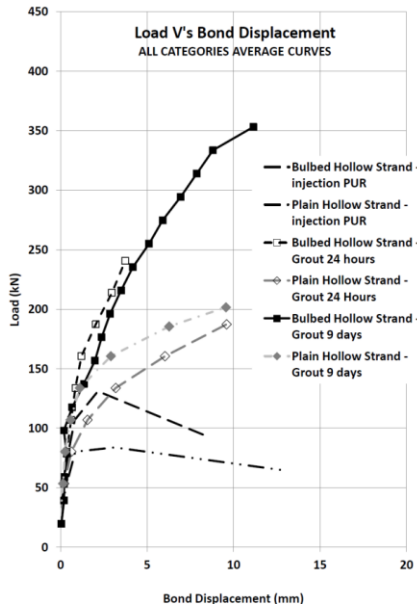


Figure 3 - Load displacement graphs, Average

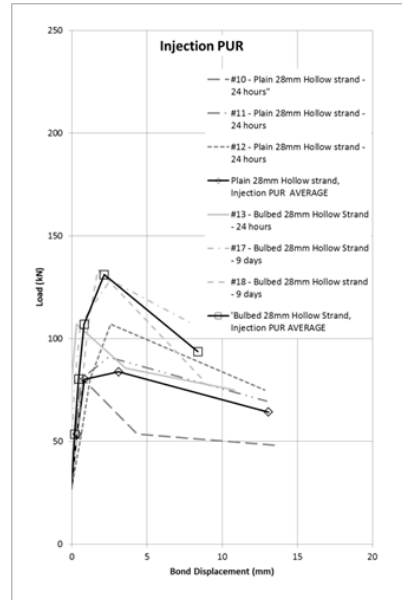


Figure 4 - Load displacement graphs, PUR

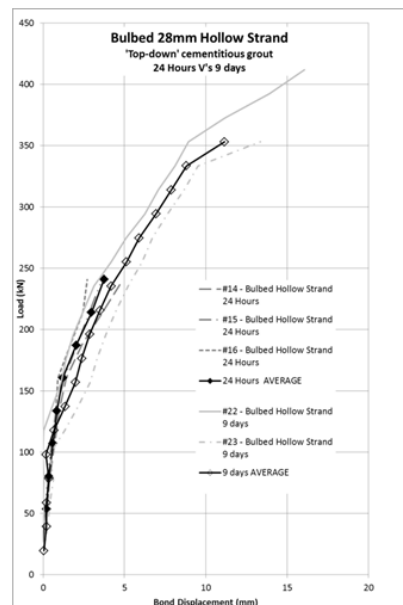
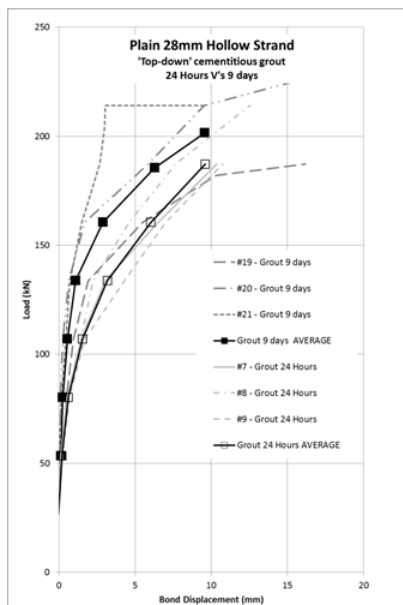
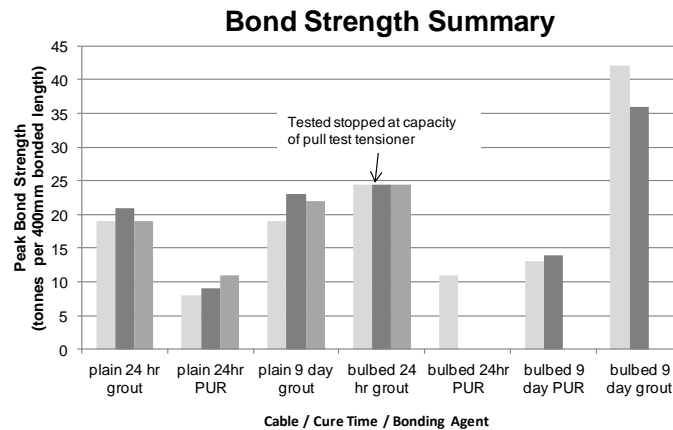


Figure 5 - Load displacement graph, cementitious grout

As shown in Figure 6, the average peak bond strength of PUR with the plain 28 mm hollow strand was 9 t per 400 mm bonded length, and for the bulbed 28 mm hollow strand was 14 t per 400 mm bonded length. The grouted test cable results for 24 h cure gave peak bond strength with the plain 28 mm hollow

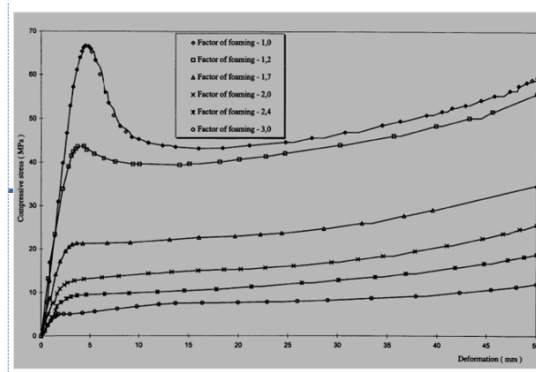
strand as 20 t per 400 mm bonded length, and for the bulbed 28 mm hollow strand was in excess of 25 t per 400 mm bonded length (test were stopped due to equipment limit). The grouted test cable results for 9 d cure gave peak bond strength with the plain 28 mm hollow strand as 21 t per 400 mm bonded length, and for the bulbed 28 mm hollow strand was 39 t per 400 mm bonded length.



**Figure 6 - Summary of bond strength results**

Little published data exists on bond strength of rock or cable bolts bonded within a drill hole using injection PUR. The most relevant reference from laboratory tests conducted by Rock Mechanics Technology (Bigby, 2005) was that *Laboratory Short Encapsulation Pull* (LSEP) tests on expandable resins showed that PUR gave very poor load transfer characteristics, but that expandable resins base on polyester could provide a much higher level of load transfer though they still did meet the acceptance criteria recommended in the draft revision of BS7861-1:1996.

The expansion PUR used in Australia for the primary goal of migration into fractured ground, especially around a longwall recovery face, typically has an expansion ratio of around two. As illustrated in Figure 7, laboratory work on strata injection PUR completed in the Czech Republic (Snuparek, 2000) highlighted the rapid decrease in compressive strength as the foaming factor increased.



**Figure 7 - Injection PUR compressive strength reduction with increased expansion ratio (Snuparek, 2000)**

PUR injection into cable bolts in the US use a product with expansion ratio of 1:1 which gives a laboratory compressive strength of 20 MPa (Faulkner, 2012). The underground bond strength testing completed at Springvale Colliery was based on current Australian practices using a PUR with expansion ratio of 2:1. Optimisation of a PUR for strata injection function and combined cable bolt bond strength could utilise only slightly modifications on the current versions of Australian approved PUR to obtain higher strength.

## CONCLUSIONS

Some Australian coal mining operations have recently used PUR injection through post-groutable cable bolts during longwall recovery support. The primary function of PUR injection in these scenarios is

reconsolidation of fractured strata, but the operational benefits of eliminating both cementitious grouting of cables, and drilling holes for PUR injection only; and instead injecting PUR into strata utilising the cable bolt is compelling.

Springvale Colliery's use of PUR injection into cable bolts during rapid response to deteriorating conditions in LW414 recovery raised the question of bond strength of injection PUR with cable bolts. The *in-situ* pull testing in Springvale Colliery coal roof with clay bands provided a comparison to cementitious grout and actual bond strengths for their strata with PUR injection into plain and bulbed cables.

Marithan N injection PUR in comparison to standard thixotropic cable bolt cementitious grout in Springvale Colliery coal roof gave a significant reduction in bond strength. The PUR compared to 24 h cured grout gave a 55% reduction in peak bond strength for the plain cable. Testing for the bulbed cable at 24 h was stopped at the 25 t equipment capacity, but even assuming this as peak strength it still has PUR being a 48% reduction in bond strength compared to grout at 24 h cure on a bulbed cable. The PUR compared to a nine day cured grout was a similar 57% reduction in bond strength for the plain cable, but a 67% reduction in bond strength for the bulbed cable.

The data presented may be useful in future testing for optimisation of possible PUR injection systems that have a dual purpose of rapid reconsolidation and a greater contribution to the load transfer of cable bolt ground support members.

### ACKNOWLEDGEMENTS

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