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VARIATION IN LOAD TRANSFER ALONG THE LENGTH OF FULLY ENCAPSULATED ROCK BOLTS, BASED ON THE INSTALLATION MIXING PARAMETERS

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ABSTRACT: The reinforcement quality of the fully resin encapsulated bolt depends on several factors, which are a combination of the bolt design configuration, bolt/hole diameter ratio and installation procedure. Gloving in bolt installation constitutes a challenging problem for effective strata reinforcement and the stability of gate roads and tunnels. A total of ten bolts were installed into ten 1.7 m long threaded steel pipes with different resin spin times, the pipes were retrieved from the installed holes in an underground mine road way roof and then cut into 100 mm long sections. The encapsulated bolts in the tube sections were then push tested. Significant variations were found in bond strength along the installed bolt length in the whole tube, with typically the top 200 mm of bolt being significantly lower (50%) in most cases due to gloving and unmixed resin components.

INTRODUCTION

An adequate rock bolting support system depends on five main physical components which are the resin, bolt, hole, machinery and rock type. Another important factor is the quality of the installation. (Wilkinson and Canbulat, 2005)

Campbell *et al.* (2004) investigation into the extent and mechanisms of gloving and un-mixed resin in fully encapsulated bolts highlighted the problems associated with quality of bolting operations. The development of a pressure front as the bolt encountering the resin cartridge as it is spun up the hole and radial expansion of the resin cartridge was suggested. Campbell *et al*. found gloving occurring over a wide range of bolt lengths, with the results showing anywhere between 30 mm to 790 mm affected. Typically the gloving affected around 500 mm of the up -hole end of the bolt.

The generalised bolt installation practice in Australian coal mines is to mix the rebar bolt through the length of the resin capsule for around 75% of the "spin time" followed by the remaining 25% of the spin time when the bolt is at the back of the hole. Operators stop mixing for the designated 'hold time' while the faster set resin hardens after which tensioning of the bolt and plate against the rock can occur. The need to improve productivity has led Australian coal mining operations to consider Spin-To-Stall (STS) bolt installation which eliminates hold time and can gain 20 s per bolt installed.

Anglo Coal pioneered the spin-to-stall system in South Africa at Goedehoop Colliery over a decade ago (Bugden, *et al.,* 2001). The spin-to-stall technique involves spinning continuously from initial mixing of the bolt through the resin capsule until the rig stalls the nut tight against the plate and rock face. The method of continually spinning a bolt until the shear pin breaks or until it tightens has been classified as an incorrect installation practice in Australia. Training of bolting operators by Australian bolting consumable manufacturers has taught that over mixing will damage the resin.

A project commenced to determine the bond strength variation along the length of a fully encapsulated bolt with varying installation techniques, including the spin-to-stall method. The resin, bolt, hole and machinery were fixed parameters with the rock replaced by steel tube. The installation variables investigated were those typically controlled by bolting operators or electronic automation programs which are mixing speed, mixing time and feed rate.

Bolts were installed into threaded steel tube underground at Springvale Colliery with a hydraulic bolting rig. The bolted tubes were subsequently transported to the University of Wollongong Rock Mechanics laboratory for further evaluation and analysis as part of an undergraduate thesis project. This

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collaborative opportunity was crucial as a learning base for similar studies to be undertaken on an ACARP funded project C21011.

STEEL PIPE METHOD OF INVESTIGATING BOND STRENGTH

Previous South African research

The study used similar methods to previous research conducted in South Africa on 20 mm diameter bolts installed through resin capsules into 800 mm long, 27 mm inside diameter threaded steel tubes. The South African study had sectioned the tubes as illustrated in Figure 1, with each section then tested by pushing the bolt through resin. The threaded steel tube ensures that the bond failure occurs between the bolt and resin interface.

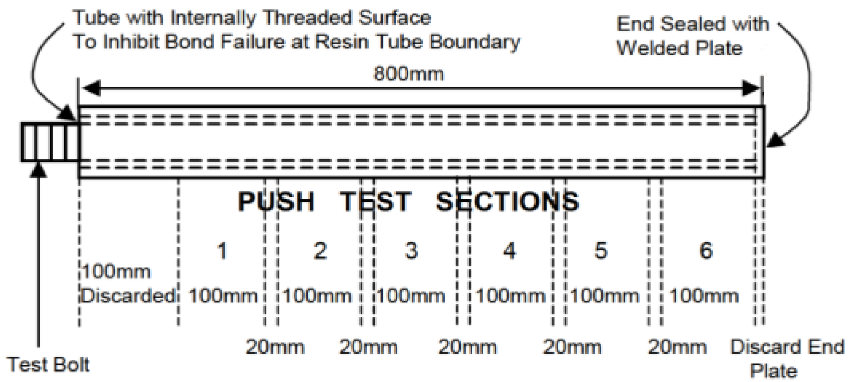

Figure 1 - Test bolt and steel pipe section (Altounyan, 2003)

The South African research used the maximum push test load for each section as the bond strength and this was plotted against the position along the bolt to come up with the "bolt bond strength profile". The trends obtained in the South African study are illustrated in Figure 2 and shows significant variation of bond strength along the bolt and also with different spin time.

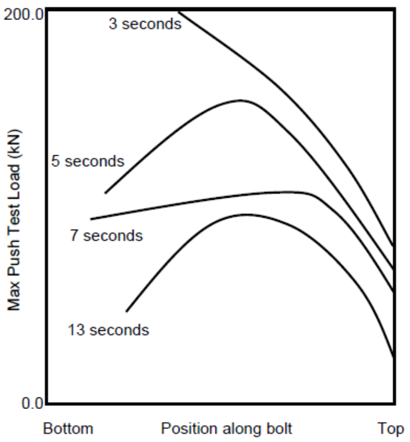

Figure 2 - South African bolt and resin 'bolt bond strength profile' (Altounyan, 2003)

The University of Wollongong has since further investigated the laboratory steel pipe push versus pull test methods. They have determined that the push test gives higher results than a pull test, and that the number of deformations (ribs) encapsulated within the length of pipe also affects the strength results (Aziz, *et al.*, 2006).

The study detailed herein maintained the use of push tests as it was most practically suited to the threaded steel tube after sectioning. The 1.7 m length of bolt and threaded steel tube was selected to simulate a 1.8 m long bolt and used dual speed 50% fast, 50% slow setting resin. The bolt selected was a 21.7 mm core diameter, 23.5 mm rib-rib diameter, JX rib profile with M24 thread as common to Australian mines.

Threaded steel pipe to simulate Australian drill holes

A review of the US Standard F432 and South African Standard SANS1532 steel pipe pull test methods led to the investigation of pipe diameters and threads to suit Australian sized bolts and drill hole. The US standard uses 25.4 mm (1") inside diameter, 32 mm (1 ¼") outside diameter pipe with a M27 x 3 mm cut thread. Both the US and South Africa commonly use 25.4 mm (1") vacuum drill bits for bolting and it is understandable that their laboratory test standards are developed to suit local products. The Australian industry standard is a 27-28 mm wet drill bit with an M24 (21.7 mm core diameter) rock bolt.

Seamless pipe of 28.5 mm internal diameter with 9.5 mm wall thickness was used for the study. A 1¼" - 7 UNC internal thread tap was selected as the minor diameter of 28.5 mm and major diameter of 32 mm suited the commercially available seamless pipe. The coarse series of thread was selected over a finer metric thread to provide good pipe/resin interface strength so that the bolt/resin interface would be the failure interface. Ten pipes were threaded and each blanked off at one end with a 300 mm x 300 mm plate welded on the other end. Holes were placed in the corners of the plate to allow bolting the pipe/plates into a borehole underground.

Underground installation of bolts into pipes

The bolting rig used underground was an electric powered mobile bolter with hydraulically powered drill motors. A 64 mm drill bit was used to form a drill hole in the roof large enough to fit the 48 mm outside diameter threaded steel tube. A drill steel was ran up and down each installed pipe with the water on to flush the pipe clean and align the rig prior to each resin and bolt installation. The rotation speed measured was 450 rpm without thrust and 420 rpm with thrust. The stall torque output was 220-250 N·m and the temperature of components was 24^{o}C.

The pipes were sectioned at the University of Wollongong Rock Mechanics laboratory into 100 mm long pieces as illustrated in Figure 3. Each section was push tested to determine the bond strength profile along the entire 1.8 m bolt/resin interface.

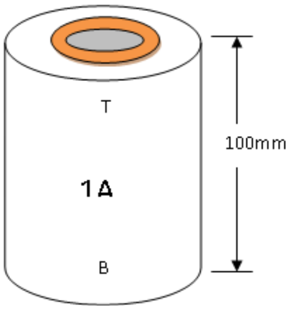

Figure 3 - Sectioned pipe with bolt and resin

The installation technique currently used in Australia could be described as the spin-and-hold method. The mixing parameters are listed below in Table 1 for the spin-and hold installations. Bolts three and four were installed with full speed rotation throughout the entire mixing. Bolt five was installed with low speed rotation during the entire mixing and bolt six had low speed during feeding of the bolt but full speed once the bolt reached the back of the hole.

Table 1 - Standard type of spin-and-hold installations

Test No	Bolt	Resin	Spin to Back		Spin at back		Hold	Length NOT encap from collar * (mm)
			Time (s)	Approx rpm	Time (s)	Approx rpm		
3	JX	J-Lok 1000 mm STS F/S oil based catalyst	9	420	3	450	All spin-and-hold installations were not tightened at all.	50
4	JX	J-Lok 1000 mm STS F/S oil based catalyst	9	420	3	450		170
5	JX	J-Lok 1000 mm STS F/S oil based catalyst	6	100	6	100		50
6	JX	J-Lok 1000 mm STS F/S oil based catalyst	6	100	6	450		200

The mixing parameters for the spin-to-stall installations are shown below in Table 2. Bolts seven and eight were installed with full speed rotation throughout the entire process. Bolts nine and ten were installed with low speed rotation during feeding of the bolt into the tube, but full speed once the bolt reached the back of the hole. Bolts 11 and 12 were installed by pushing the bolts through the resin without rotation, but full rotation was applied right through to stall once the bolt had reached the back of the hole.

Table 2 - Spin-to-stall installations

Test No	Bolt	Resin	Spin to back		Spin at Back			Thread tail below nut (mm)	Length NOT encap from collar * (mm)
			Time (s)	Approx rpm	Time at pin break (s)	Time at Stall (s)	Approx rpm		
7	JX	J-Lok 1000mm STS F/S oil based catalyst	8	420	28	35	450	120	100
8	JX	J-Lok 1000mm STS F/S oil based catalyst	8	420	29	33	450	76	170
9	JX	J-Lok 1000mm STS F/S oil based catalyst	6	100	18	22	450	80	150
10	JX	J-Lok 1000mm STS F/S oil based catalyst	6	100	13	17	450	48	180
11	JX	J-Lok 1000mm STS F/S oil based catalyst	6	0	10	12	450	52	110
12	JX	J-Lok 1000mm STS F/S oil based catalyst	6	0	11	14	450	48	0

RESULTS AND DISCUSSIONS

There were 150 x 100 mm long sections push tested, each with its own load displacement curve. The load displacement curves varied for each section but would generally be one of the types of loading illustrated below in Figure 4. Type A sections loaded rapidly to a peak load and residual loads held steady but lower. Type B sections loaded rapidly to an initial yield and subsequently loaded to a higher peak residual load before dropping load. Type C was much softer loading but maintained a residual load. The variations in load displacement curves are clearly evident in Figure 5 for typical sections of the entire bolt length tested. Also shown in Figure 5 the cross-sectional view of various bolt sections, clearly there were some spots of weak resin encapsulations and the severity of the poor bonding varied for different installations conditions.

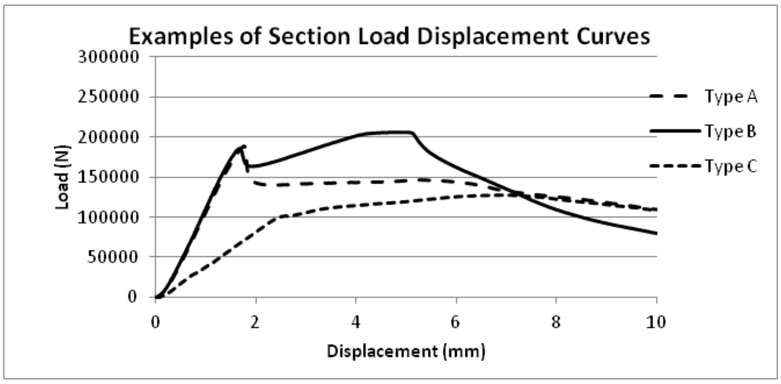

Figure 4 - Examples of load displacement curve types for the 100 mm push test sections bond strength profiles

The maximum load for each section within 10 mm displacement was taken as the peak load. The bond strength profile was determined for each bolt, with "best fit" curve applied as shown in Figure 6.

Bolts three and four were the current Australia typical spin-and-hold installation technique. The quality of bolts three and four was very high, with the gloving confined primarily to section A, and minimal air bubbles within the resin annulus. The average peak strength of these two bolts was used to compare the effect of differing installation methods in the other groups of bolts, being 137 kN per section, and called the average baseline strength.

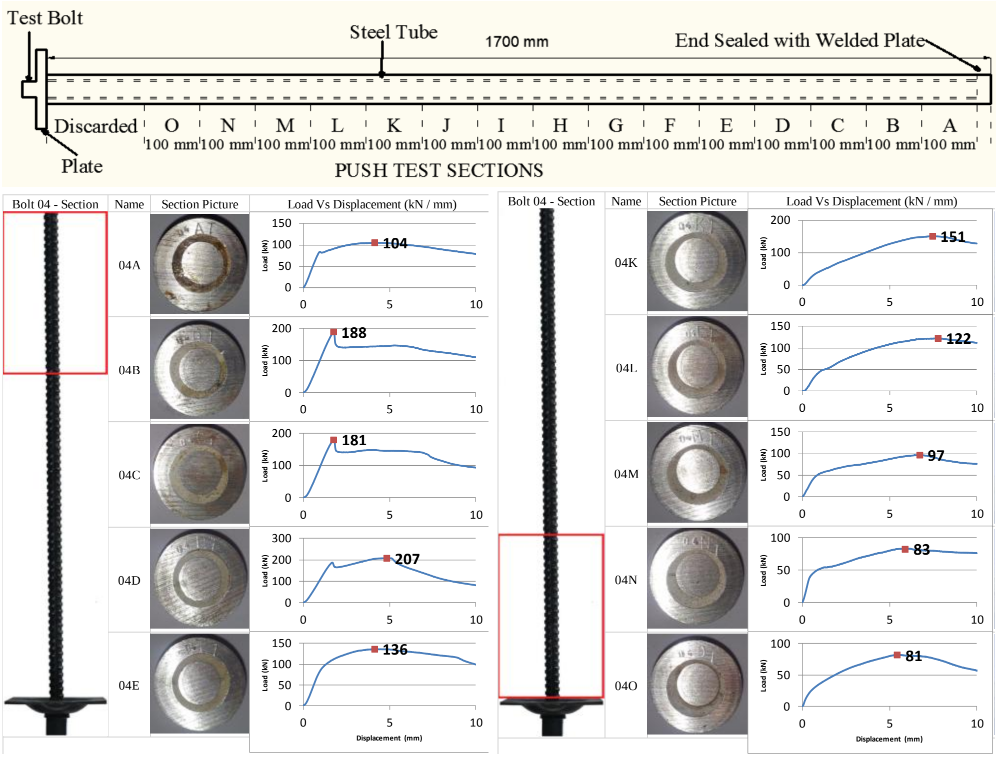

Figure 5 - Load transfer capacity of different 100 mm long sections on one bolted tube

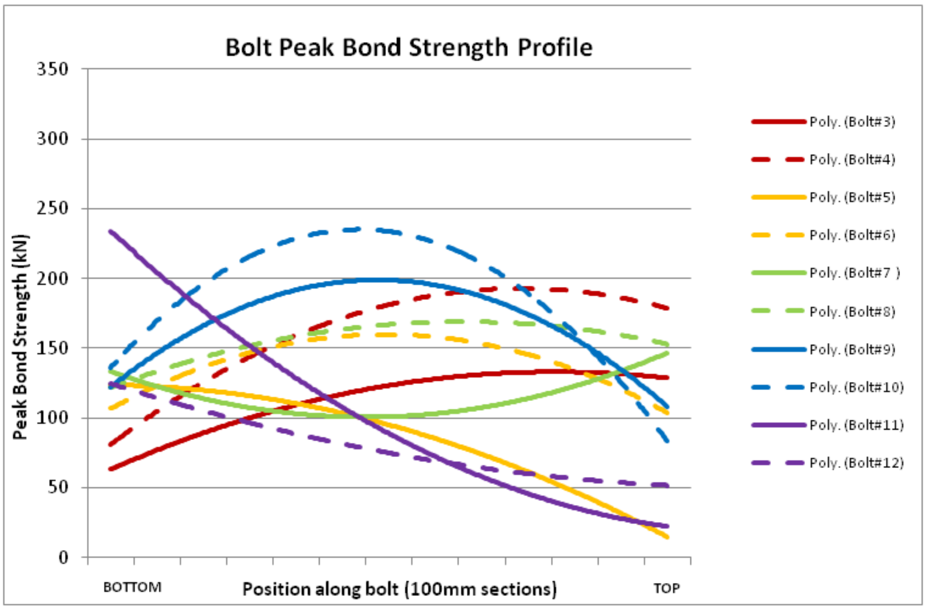

Figure 6 - Peak push load per section per bolt

Bolt five was slow rotation under-mixing and was the worst performing bolt, testing at 62% of the average baseline strength mentioned above. Visual inspection after testing revealed many flaws in the resin annulus along the entire length of the bolt. In the upper four sections there was excessive gloving that had completely enclosed the bolt, providing a much lower bond strength performance and significantly lowering the peak loads. Below the top 500 mm, the gloving had reduced to moderate or minimal, but there were air bubbles present in the resin annulus.

Bolt six was a spin-and hold installation with only a slow rotation during feed aimed at reducing over mixing of the bottom of the resin capsule. For bolt six, the overall quality was much greater than that of bolt five. But similar to bolt five, the top 200 mm had moderate to excessive gloving, and the gloving had completely enclosed the bolt section. Most of this bolt below the top 300 mm achieved the peak load between 5 mm and 10 mm displacement within the 100 mm sections.

Bolts seven and eight were a spin-to-stall with full rotation speed from the start to stall. In comparison to the baseline average strength all were directly on par. It did appear that the resin was over-mixed and lowered the average strengths. There was minimal gloving evident in both bolts.

Bolts nine and ten were spin-to-stall with slow rotation during feed aimed at minimising over mixing in the bottom part of the resin capsule, but full rotation was applied once the bolt reached the back of the hole and up until stall. When comparing bolts nine and ten to the baseline bolts, the average peak bond strengths were 28% higher, the average bond strengths were 44% higher. This installation method produced notably superior strengths, and when compared with bolts seven and eight, it is presumed that the slower mixing speed during installation prevented over-mixing of the resin but still enough to properly shred the resin capsule film.

Bolts eleven and twelve were pushed through the resin capsule without spinning then spun at full speed up to stall. Comparing bolts eleven and twelve to the baseline bolts; all three average strengths were notably lower than the average baseline strength. There was a shift in average strength in favour of the lower half of the bolts, and it is evident from inspection after testing that this method did not shred the resin capsule properly during the initial stages of mixing, therefore allowing for significant gloving in the upper half of the bolts.

Due to the variation in the 100 mm long section load displacement curves illustrated in Figure 4 further analysis was conducted by taking the load at 2 mm displacement for each section. Also, a method of bond strength being determined at the point of the gradient reaching 20 kN/mm was used.

Figure 7 below shows the average strength for each bolt using the various criteria; 1) Bond strength for each 100 mm section as the point the curve reaches 20 kN/mm gradient. 2) Peak bond strength for each 100 mm section, which can occur at any displacement depending on the shape of the curve. 3) Bond strength at 2 mm displacement for each 100 mm section.

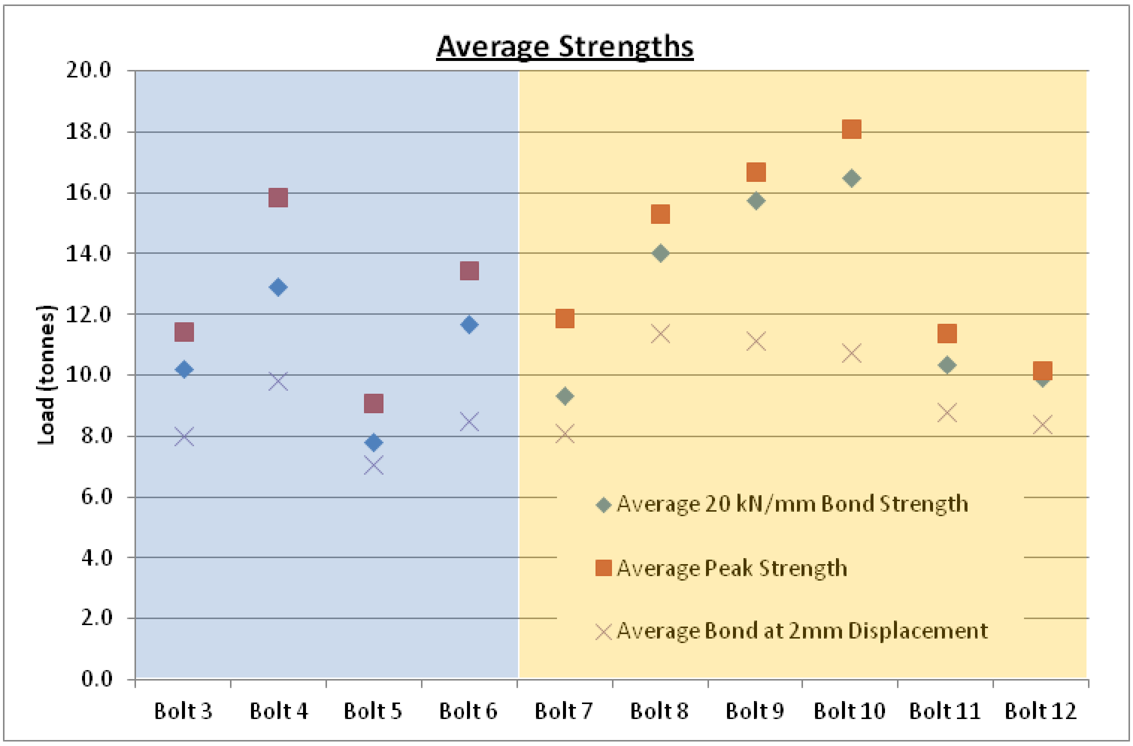

Figure 7 - Average push load per bolt tested at the stiffness of 20 kN / mm, at peak bond strength and peak bond strength within 2 mm displacement

CONCLUSIONS

There is significant variation of bond strength along individual rock bolts, with typically the top 200 mm of bolt being significantly lower (50%) in most cases due to gloving and unmixed resin components.

The typical Australian installation technique of spin-and-hold (Bolts 3 and 4) gave an average peak bond strength of 137 kN per 100 mm long push test section, which was used as a baseline for comparison of the other techniques.
Gloving and under mixing greatly reduced bond strength with slow rotation spin-and-hold (bolt five) and pushing through the capsule without spinning (Bolts 11 and 12) highlighting these effects.

Spin-to-stall installations (Bolts seven to ten) produced average bolt bond strengths, using the various presented criteria, equivalent to or better than spin and hold installations.

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