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Pumpable two-part resin cable bolt bonding material tests

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PUMPABLE TWO-PART RESIN CABLE BOLT BONDING MATERIAL TESTS

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ABSTRACT: The Australian underground mining industry extensively uses thixotropic cementitious grout as a bonding agent for cable bolts. Grout is very effective as a bonding agent but is prone to issues with consistently achieving full column encapsulation and has operational issues impacting production. An economically viable two-part resin bonding agent is being investigated by Jennmar which offers some operational advantages. This paper explores the bond strength evaluation of the two-part resin against cementitious grout.

INTRODUCTION

Cementitious cable bolt grout is the bonding material used for over 90% of cable bolts used in Australia underground mining. In Australian coal mining, the cementitious grout is a thixotropic version pumped 'top-down' and has a 28 day UCS of 80 MPa. Publications exist on bond strength performance of these cementitious grouts compared to two-part resins (Craig and Holden 2014, Hagan 2014). The application of cementitious grout in underground coal mines is typically by way of a compressed air driven 150 litre paddle mixer with 3.45 MPa (500 psi) output piston pump. The advantages and disadvantages of the cementitious grout are listed in **Table 1**.

Table 1: Advantages and Disadvantages of Cementitious Cable Bolt Grout

Advantages	Disadvantages
Very high strength	Dust hazard during mixing
Portable compressed air driven pump and mixer	Slow curing time
Relatively low pump pressures required	Strength is sensitive to operator water addition
Simple combination of powder with water	Downtime due to mixing and cleaning required

A main disadvantage of cementitious grout is the slow curing time. Many mines have to cease production in unique situations while cable bolt grout is curing for 24 – 48 hrs to ensure secondary support is adequately performing before such things as widening roadways or removing longwall shields. The other hindrance to production is cement dust generated during mixing, with some mines excluding personnel from the cement dust exposure.

Jennmar is currently investigating a two-part rapid setting resin as an alternative cementitious grout to overcome its shortcomings. The two-part resin under investigation is a modified formulation of the well-studied mastic and catalyst used in common resin capsules used for anchoring rock and cable bolts in Australian mines. This formulation uses polyester based resin with inorganic fillers, such as limestone, comprising approximately 70% by weight. The advantages of this two-part resin is fast cure time, dust elimination and no cleaning required as the resin components can sit in the pump and lines for months and remain unreacted.

DEVELOPMENT OF THE TWO-PART RESIN FORMULATION

Australian rock bolt resin capsules enclosed within a plastic film are typically 20% catalyst volume for water-based catalyst. To aid mixing and pumping of the two-part resin, it was formulated at a 2:1 ratio by volume. The result was an increase in catalyst ratio of the pumpable resin to 33%, which reduced the uniaxial compressive strength (UCS) to 20-40 MPa compared with a capsule UCS of 50-60 MPa. This 2:1 ratio was a requirement of the piston pump design selected, and the formulation strength reduction was a compromise to achieve pumpability. The ideal mastic to catalyst ratio for mixing a pumpable resin is 1:1 by volume, however it was decided that would further compromise strength when compared to cementitious grout used in Australian coal mines.

The main operational advantage of the two-part resin compared to cementitious grout is higher early strength. Laboratory tests of UCS (50 mm cubes) gain over time were conducted and resulted in the curves shown in **Figure 1**. In the laboratory, the resin and cement grout are perfectly mixed by hand to

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obtain ideal strengths. It takes cementitious grout approximately 50 hours to reach the same strength that two-part resin reaches in 6 hrs. The two-part resin reaches approximately 30 MPa UCS within 6 hrs, which offers strengths similar to the rocks found in coal measures roof strata. It was postulated that cable bolt bond strength might reach acceptable levels within a coal measures rock even at the lower strength compared to cementitious grout.

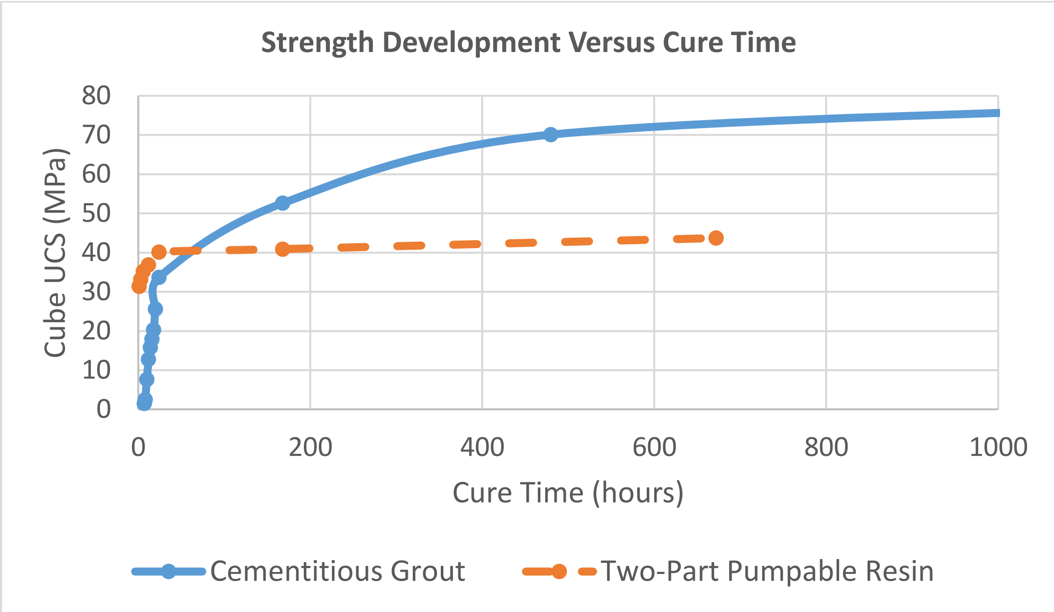


Figure 1: UCS strength gain versus cure time

Encapsulation testing was completed on vertically hung 8 m long hollow centre tube 70 tonne capacity cable bolts. It proved difficult to obtain resin return within a suitable pumping time of less than two minutes. The 25.4 mm (1") diameter resin line and 19 mm (¾") diameter catalyst lines were kept to a maximum 10m length, and then the centre tube of the cable bolt was 13 mm inner diameter over 7 m length. Three different resin formulations were trialled to obtain a suitable version that could be pumped the required distance to reach and encapsulate an 8 m cable bolt in a reasonable timeframe. This formulation suitable for pumping Australian coal mining cable bolts was used for the subsequent load performance testing.

LABORATORY SHORT ENCAPSULATION PULL TESTS

The University of New South Wales (UNSW) had developed a standardised laboratory short encapsulation pull test method (LSEPT) as first described by Hagan et al 2014. This method was used to test various Australian cable bolt and bonding materials over subsequent years of research at UNSW. Jennmar constructed its own in-house LSEPT facility based on design details provided by UNSW. The basic principle of the LSEPT is illustrated in **Figure 2**.

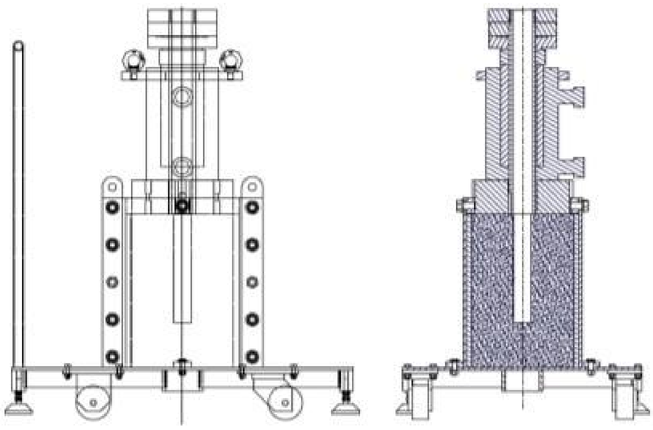


Figure 2: Laboratory LSEPT (Hagan, 2014)

The LSEPT results for the two-part resin was 10-12 t on the one birdcage in 320 mm encapsulated. The load versus displacement graph for two tests is shown in **Figure 3**. The two-part resin used was hand mixed which would have provided higher strength compared to mixing through a static mixer.

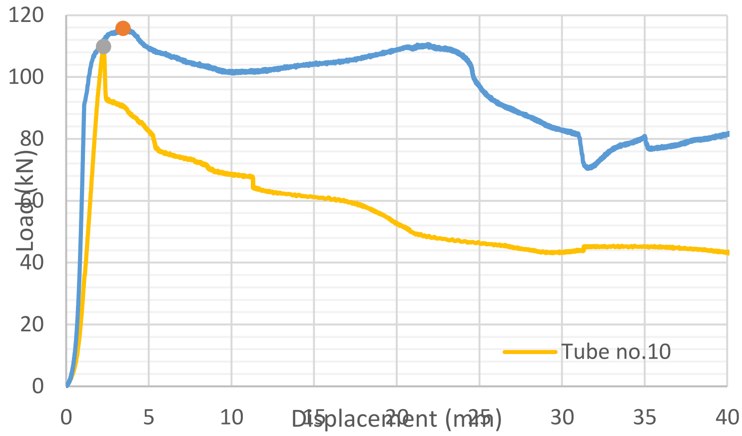
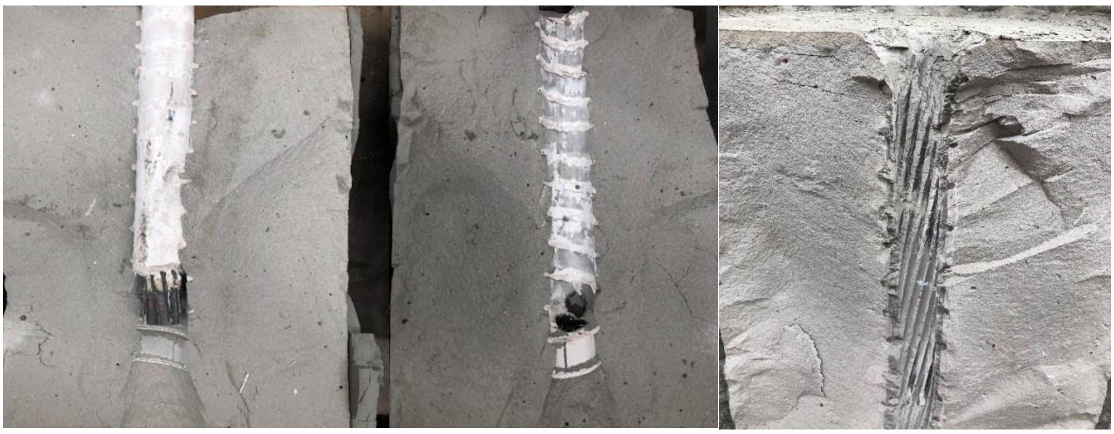


Figure 3: Two-part resin LSEPT results

The concrete used to simulated rock in the LSEPT had a UCS of 60 MPa. The concrete was split open after the testing for inspection as shown in **Figure 4**. It can be observed in **Figure 4a** how the LSEPT rifling is made using tubing wrapped around a cylinder. **Figure 4b** demonstrates how the lower strength two-part resin fails by shearing off the rifling rather than the target bond strength between the cable and resin interface. The stronger cementitious grout shown in **Figure 4c** can be seen to fail on the desired cable/grout interface. It was proposed that the two-part resin was not suited to the standardised LSEPT method due to the artificial rifling created in the laboratory not being representative of the rifling in an in-situ drill hole. In-situ underground testing was pursued as the next stage of evaluation for the two-part resin.



a) **b)** **c)**

Figure 4: LSEPT block opened after testing

UNDERGROUND SHORT ENCAPSULATION PULL TESTS

The advantage of underground testing is the larger number of tests that can be done in one location in a short period of time. An in-situ testing program was developed to compare two-part resin against cementitious grout; it also allowed testing short encapsulation pull out strength versus cure time. The in-situ testing was aimed at verifying the advantage of high early strength gain from two-part resin.

The in-situ testing was completed within a targeted anchorage horizon consisting of uniform strong un-fractured sandstone, away from the unconfined surface zone of the roadway. A total of 20 short encapsulation pull tests were completed. The two-part resin was able to be pull tested after 1 – 3 hours, then comparison two-part resins versus cement grout were conducted at 24 hours, 7 days and finally 76 days, which ensured in excess of full 28 day cement cure was achieved.

It was assumed that bond strength and peak loads would be below the 50 tonne capacity of the in-situ pull testing hydraulic cylinder when only encapsulated for 500 mm length. The 50 t hydraulic cylinder was not fitted with anti-twist devices as described by Craig and Holden, 2013. This meant displacement would be higher as the cable bolt free-length unwinds slightly under load, resulting in a lower stiffness measurement compared to if anti-twist was used. It should be noted that anti-twist is within the design of the LSEPT of Hagan, 2014. The load testing was stopped at 45 t whilst underground to maintain a safety factor with personnel reading displacement with an analogue dial gauge.

Installation

The cables bolts were 2 m long with de-bonding material only allowing bonding of the top 500 mm of cable with a single birdcage. The top 500 mm of drill hole was drilled using a twin-wing 45 mm PCD drill bit, and the bottom 1.3 m of drill hole was reamed out using a 65 mm diameter reamer. The cable was placed 1.8 m into the roof strata, leaving 200 mm of cable tail for the hydraulic pull tester to grab.

The cementitious grout was mixed with a standard coal mine paddle mixer and pumped using a piston pump. Cube samples were taken of the grout from the end of the pump out line for subsequent UCS testing. The two-part resin was pumped using a Jennmar designed large bore and single stroke hydraulic piston pump, which consists of two separate large pistons that inject mastic and catalyst through two separate lines. The mastic and catalyst come together at a Y-piece located 10 m from the pump close to the cable bolt. A static mixer is positioned immediately after the Y-piece and acts to mix the two components before entering the one-use 3 m long injection hose attached to the cable bolt centre hollow tube. Resin cube samples were taken from the end of the 3 m long injection hose for subsequent UCS testing.

Both resin and grout were pumped to the top of each cable bolt and down the outside until material appeared at the collar of the hole. Laboratory testing of static mixers had previously revealed that longer mixer elements produce better mixing as expected, but the longer element also greatly increase resistance to pumping and can hinder resin return when pumping 8m long cables. The static mixer element used produced 8 turns of mixing, which has been shown to produce adequate UCS strength of 28 MPa but not ideal mixing like that achieved by hand mixing of 40 MPa.

The cube samples of bonding materials were taken on the day of installation. After the samples had set firm, they were transported to Jennmar's research and development facility in Sydney for UCS testing. The cube samples were removed from the moulds and left to cure in air at ambient temperature. The aim of the cube curing method was to represent the curing within the dry roof strata where testing was taking place underground.

Results

Table 2 summarises the underground short-encapsulation pull test results. The bond strength was taken as the point on the load versus bond displacement curve where the gradient reduced below 20 kN/mm. The peak load was taken as the maximum load.

The results of the 1.5 – 2 hr tests on the two-part resin were lower than expected which could be a number of factors, such as temperature and mixing of the polyester mastic and catalyst. It was noted that the strength was increasing with the last pull test at 2 hrs.

The most important test result was the 24 hr test of the resin versus the grout for early strength assessment. The short encapsulation pull tests (SEPT) results show that cementitious grout was double the bond strength and 36% higher peak strength at 24 hours cure, whereas the bonding material UCS results measured a 76% increase between the resin and grout. A contributing factor to the results is the low UCS of the two-part resin indicated by the cubes taken on the day of installation. It is likely the level of mixing produced by the static mixer was lower than expected and the resin only reached half of its idealised laboratory UCS. The 7-day tests showed inconsistency with the two-part resin varying by over 100% compared to the grout, which gave an improvement over the 24-hour tests as the cement strengthened. The resin SEPT results did not strengthen between 24 hours and 7 days, with inconsistency recorded. This is again likely to be mixing efficiency of the static mixer being low compared to laboratory tests. The 76-day tests followed a similar trend as the 7-day tests. The UCS of the bonding material was shown to impact the SEPT results, with the relationship shown in **Figure 5**.

Table 2: Results Summary Underground Pull Tests

Test#	Bonding Material	Cure Time	Bonding Material UCS (MPa)	Bond Strength (tonnes)	Peak Load (tonnes)
1	Two-Part Resin	1.5 hrs	Not Tested	1.9	3.4
2		1.75 hrs		3.8	5.8
3		2 hrs		7.7	13.4
4	Two-Part Resin	24 hrs	17	12.5	25.9
5				18.2	28.8
6				18.2	28.8
7	Cementitious Grout	24 hrs	30	30.7	37.4
8				25.9	38.4
9				33.6	38.4
10	Two-Part Resin	7 days	17	24	26.9
11				14.4	31.7
12				11.5	16.3
13	Cementitious Grout	7 days	51	32.6	46.1**
14				42.3	45.1**
15				44.2*	44.2**
16	Two-Part Resin	76 days	17	25	26.9
17				11.5	14.4
18	Cementitious Grout	76 days	70	42.3	44.2**
19				42.3	44.2**
20				42.3	44.2**

*Test stopped before bond yield, **Test stopped before peak load reached

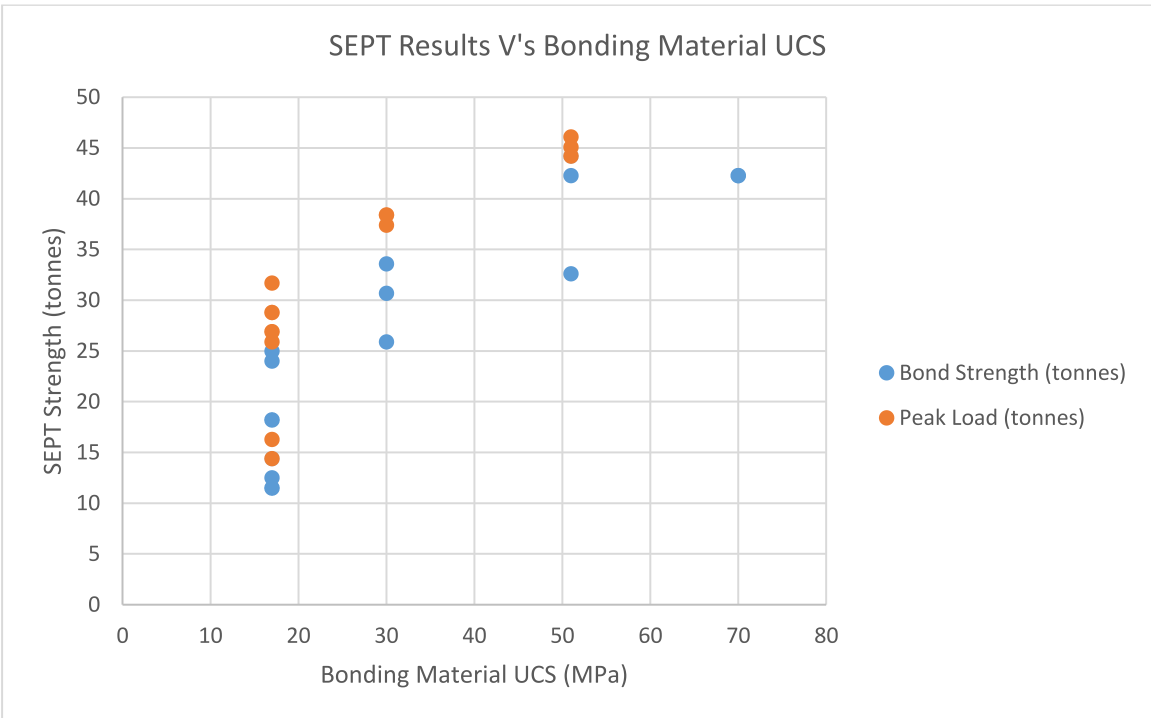


Figure 5: SEPT Strength Versus Bonding Material UCS

An example of the load versus bond displacement curve for the underground testing of two-part resin is shown in **Figure 6**. When compared to the LSEPT of two-part resin in **Figure 3**, it can be theorised that the underground short encapsulation pull tests did not have the same problem of the rifling shearing off as found in the LSEPT. Drilled boreholes are shown in Aziz, 2004 to have very wide rope thread type rifling compared to the small diameter artificial rifling of the LSEPT, which seems to have prevented the resin-rock interface failure and promoted the cable-resin interface failure.

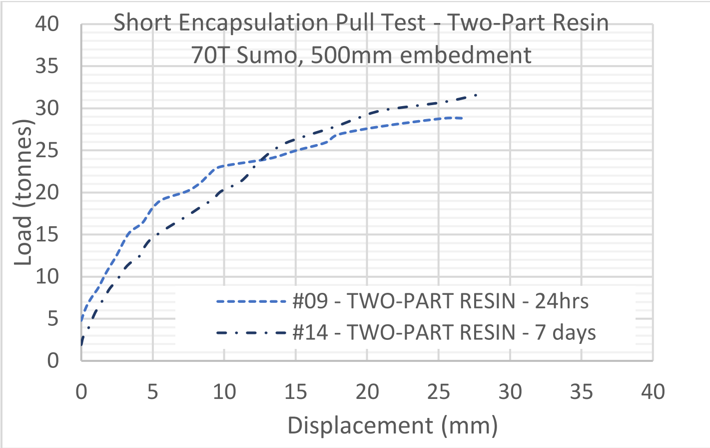


Figure 6: Two-part resin In-situ SEPT results

CONCLUSIONS

A two-part polyester resin was formulated that could be pumped 10m horizontally to an Australian coal mining type cable bolt and then through the 13mm diameter centre tube to achieve top-down encapsulation. The two-part resin contained over 70% limestone fillers by weight, which made pumping and mixing through a static mixer a challenge.

The lower strength two-part resin proved not suitable for Laboratory Short Encapsulation Pull Tests (LSEPT) due to shearing of the artificial rifling molded in the laboratory. The in-situ Short Encapsulation Pull Tests (SEPT) gave a more regular shaped load versus displacement curve, indicating the correct cable-resin bond failure.

The lower strength two-part resin formulation gave lower SEPT results compared to the high strength cementitious grout used in coal mining. The underground installation involved pumping the two-part resin through a helical static mixer, and this would be the most likely cause of the lower than expected strength and consistency achieved.

The high strength cementitious grout achieved 30 tonne per 500mm bond length at 24 hours, and 40 tonne at 7 days. This data suggests the early strength gain in top-down cable bolt grout used in Australian coal is very good and exceeds the two-part pumpable resin developed during this project.

The experiments highlight some challenges in pumping 70% limestone filled polyester resin, and the importance of evaluating the system in-situ instead of relying on laboratory material properties and testing methods.

ACKNOWLEDGMENTS

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