2021

Benchmarking study by laboratory load transfer testing along full resin encapsulated rock bolts

Sabitha Sasi
Jennmar Australia

Peter Craig
Jennmar Australia

BENCHMARKING STUDY BY LABORATORY LOAD TRANSFER TESTING ALONG FULL RESIN ENCAPSULATED ROCK BOLTS

Sabitha Sasi[1] and Peter Craig[2]

ABSTRACT: The primary ground support used in Australian underground coal mines is a rebar rock bolt anchored to the rock mass using polyester resin capsules. The key objective of this research project was to benchmark different types of Australian rockbolt resin capsules, including relatively new formulations. Laboratory test methods were developed based on previous studies conducted in South Africa and subsequently at the University of Wollongong, which used 1.8 m JX bolts for installation in internally threaded steel pipes that simulated the borehole. The encapsulated bolts were cut into 80 mm long sections for push testing to obtain around 20 data points from each bolt. Different resin formulation variables were tested; these included three types of limestone fillers and two types of catalyst. The load transfer capacity ofdifferent resins were determined by evaluating the bond strength, peak strength and area under the push test curve. Significant variation in load transfer capacity was found along the length of all 1.8 m bolts tested. The load transfer capacity and its variations along the bolt length were evaluated to be a characteristic of the type of resin formulation tested. Some resin formulations produced upto 20% higher load transfer capacity with better consistency along the length of the bolt. Results from more than 300 push tests were used to assess and validate this study. The findings from this detailed research project can be used for a better understanding of the ground support performance of different Australian resin capsules.

INTRODUCTION

Ground support systems are a critical aspect in the field of underground mining. There have been continuous research and development in this field to optimise underground roadway development rates and to reduce the risk of collapsing roadways. The primary ground support technology includes a rebar rock bolt anchored in a grouting medium such as a polyester resin.

Development of resin capsules had revolutionized underground mining industry. Resin capsules can provide full-length bolt anchoring with a safer and cost effective method. Unlike cement grout, resin technology compliments roof support by providing the benefit of chemical bonding within seconds of installation. Various formulations of resin mastic and catalyst were developed to cater to the requirements of different mining conditions. Since the last 10 years, about six different J-Lok primary resin formulations have been developed in Australia. Manufacturers typically use laboratory specimens in different shapes and sizes based on country of origin or acceptable standards, to determine the mechanical properties of resins without reflecting on the effect of bolt rib mixing the resin components or the presence of capsule film (Hillyer, et al., 2013). However, there is no Australian laboratory standard for testing the mechanical performance of the resin capsule based on mixing of its component with the installation of ribbed rebar in a drilled holed (Aziz, Nemcik, Craig, & Hawker, 2014).

The amount of load that can be potentially transferred from the strata to the bolt through the resin encapsulation is determined by the mechanical interlocking between the resin, bolt and the strata. This property can only be evaluated post rockbolt installation. Underground short encapsulation pull tests are conducted periodically to verify the mechanical capacity of the rockbolt-resin system. However, this neither provides a standardised comparison between the different resins available in the Australian market nor gives adequate technical information to understand the variations in load transfer capacity of the resin along the full length of the encapsulation.

With the number of variations available in resin formulations today, it is high time to develop a standardised test method to identify the load transfer capacity of resin capsule post installation as well

[1] Mechanical Engineer, Jennmar Australia. Email: ssasi@jennmar.com.au Tel: +61 426 840 171
[2] National Manager-Coal, Jennmar Australia. Email: pcraig@jennmar.com.au Tel: +61 419 018 998

as its consistency along the full length of the installed rockbolt. Hence, the primary objective of this study is to benchmark the performance of different types of resin capsules available in the Australian market. Based on previous studies conducted in South Africa and subsequently at University of Wollongong, as well as considering the rockbolt installation parameters, Laboratory Short Encapsulation Push Tests (LSEPUT) were used to benchmark the different types of resins available in the Australian market.

ROCKBOLT AND RESIN CAPSULE INSTALLATION

The conventional method of coal mining rock bolt installation is by spinning a rock bolt through a resin capsule inserted into a drilled hole of diameter nearly 30% more than the bolt diameter. Spinning of the rockbolt facilitates the shredding of the resin capsule plastic film as well as promotes the mixing of the catalyst and resin mastic by the bolt ribs. The manufacturers recommended spin time is controlled by spinning through the length of the resin capsule for about 75% of the spin time and spinning the remaining 25% of the spin time with the rockbolt at the back of the drilled hole. The bolt is held stationary for tens of seconds to allow the resin to harden before applying tension, this is classified as the spin and hold method.

The recent developments in the resin capsule technologies have introduced the spin to stall resin formulations. These resin capsules are installed using spin-to-stall methods. This method negates the need for a hold time and reduces the overall installation time to improve roadway development times (Emery, Craig, Sykes, Canbulat, & Naylor, 2015).

Resin capsule comes in a sausage shaped plastic and contains the polyester resin with limestone fillers and a catalyst separated by a thin film of plastic lining. Three main types of limestone fillers in polyester resin mastic along with a combination of two different types of catalysts are used under the J-Lok Australia brand name. The range of limestone fillers include; Grit, Standard and Low Insertion Force (LIF) fillers. The two different types of catalysts used in Australian industry are water-based catalyst and oil based catalyst. Both these catalyst have the same limestone filler but have different concentrations of initiator, which is benzoyl peroxide. In order to get optimum levels of cured resin properties, the catalysts are used in different ratios with the mastic based on its concentration of benzoyl peroxide. Hence, in the case of oil-based catalyst only 7% of the capsule consists of the catalyst whereas for water-based catalyst, 20-30% of the capsule consists of the catalyst.

LABORATORY SHORT ENCAPSULATION PUSH TESTS

The original South African study was conducted on rock bolts of 20 mm diameter, which were installed through resin capsules into internally threaded steel tubes of 27 mm internal diameter and 800mm in length. The bolt-installed steel pipes were then cut to 100mm sections and the bolt waspushed through the resin to test the strength of encapsulation in each of these sections (Altounyan, 2003).

A test method was used based on this study to incorporate the Australian parameters of rockbolt installations. Laboratory Short Encapsulation Push Tests were conducted in four stages as given below:

(a) Stage 1: Rockbolt installation in internally threaded steel tube.

(b) Stage 2: Cutting of encapsulated sections into twenty sections of 80mm each.

(c) Stage 3: Push testing the rockbolt through each of the encapsulated sections.

(d) Stage 4: Result Evaluation and benchmarking of the different resins in the Australian market.

A rockbolt of 21.7 mm core diameter installed in a hole drilled with a wet drill bit of 27 – 28 mm is the Australian industry standard. Hence, 1.7 m long seamless steel pipe with internal threads of 7/8 BSPF and 5mm in thickness was used to simulate Australian underground mine boreholes. One end of the steel tube was welded close (back of the borehole) and the other end of the tube was welded on to a steel plate with a centre hole to insert the bolt. Two holes of 1mm each were drilled about 10mm from the back of the tube on its opposite sides. This provided enough gap for any air to escape but not enough to lose any resin while spinning the bolt to the back of the tube through the resin capsule. In the case of installing low insertion force (LIF) resin capsules, due to its very fine particle size, the two standard holes of 1mm each were drilled at the back of the tube and covered with a cotton cloth. This provided just enough gap for air leak but not enough for resin loss.

In order to limit the test variables to only different formulations of resin mastic and catalyst, a standard rockbolt and capsule were used for installation in the internally threaded steel pipe. The M24 JX bolt with a length of 1.8 m and core diameter of 21.7 mm was used as the standard rockbolt for installation along with different resin formulations in capsules of 24 mm diameter and 1200 mm length. The resin capsules were installed at a recommended temperature of 20 - 25 degree Celsius. All the resin capsules used were made in 50:50 dual set speed ratios.

Installation of JX rock bolts

The rockbolt-resin system was installed in the threaded steel tube using a Joy HFX surface drill rig at J-Lok resins testing facility. The HFX, HDR drill rig had a rotary motor with a speed range of 500 – 600 rpm. The installation method and spin time were determined as per the recommendations for the type of resin installed. Two sets of tests were conducted for each type of installation parameters.

Preparation of fully encapsulated push test sections

Following the bolt-resin installation, the steel pipe was cut into twenty sections of 80mm each for push test. The 80mm length ensured that each section would encapsulate three bolt ribs and hence give a standardised comparison between all the push test results. All sections were examined for full encapsulation, gloving and other factors that could affect its load transfer capacity. Before push test, these sections were machined on both ends to remove any sharp edges or burrs and to ensure that it is seated perpendicularly for push tests.

Push Tests

In the interest of getting consistent and quality results, only fully encapsulated sections were push tested and its results were evaluated to study the load transfer capacity for the different formulations of resins tested. All sections were examined before and after push tests for any signs of gloving, air bubbles or uncured resin encapsulation.

A steel plate with a push test spigot of 18 mm diameter at its centre and a cylindrical base plate with a seating for the steel tube and hole for the bolt displacement were custom manufactured for the push tests. In the interest of analysing the failure between the bolt and resin interface, the diameter of the push test spigot was kept smaller than the bolt core diameter of 21 mm.

The push test setup was assembled as seen in the Figure 1. The push test spigot was placed over the centre of the encapsulated bolt and then loaded at a rate of 1 mm/min up to 10 mm of displacement. An inbuilt data logging software was used to record the 'load vs displacement' data points for every 0.05 seconds from the push tests. The data points were extracted into excel and compiled to evaluate the load transfer capacity and its variations along the length of the bolts.

Figure 1: Push test setup

Result evaluation

Load vs displacement curves were generated for all the tested sections. Based on previous studies and traditional methods of result analysis different methods were considered to analyse these push test results and hence benchmark the load transfer capacity of the different types of resins. These included the average bond strength, average peak strength, average work done, and Load Transfer Index (LTI). These results were also used to evaluate the variations in load transfer capacity along the length of the bolt and its effect on the entire system performance.

Fourteen different tests were conducted and used for the purpose of this benchmarking study. These included six different variations in resin and catalyst formulations. The resin formulations were identified as per the manufacturers naming conventions, which are given in Table 1 as Resin Id.

Table 1: Resin formulations and installation methods used in the benchmarking study

S.No	Test Id	Resin Id	Resin Formulations		Spin To Back (Secs)		Spin At Back (Secs)		Hold Time (secs)	Set Speed (50:50)
			Limestone Fillers	Catalyst	Ideal	Actual	Ideal	Actual		
1	Test4	JLD	Standard	Oil based	12	13	3	4	30	Superfast: Slow
2	Test8	JLD	Standard	Oil based	12	13	3	3	30	Superfast: Slow
3	Test3	JL5D	Standard	Water based	12	13	3	3	30	Superfast: Slow
4	Test7	JL5D	Standard	Water based	12	15	3	3	30	Superfast: Slow
5	Test5	JG5D	Grit	Water based	12	13	3	3	30	Superfast: Slow
6	Test9	JG5D	Grit	Water based	12	14	3	3	30	Superfast: Slow
7	Test2	JGD	Grit	Oil based	12	13	3	3	30	Superfast: Slow
8	Test13	JGD	Grit	Oil based	12	13	3	4	30	Superfast: Slow
9	Test11	STSA	Grit	Oil based	12	15	Spin till pin breaks and rig stalls			Superfast: Slow
10	Test12	STSA	Grit	Oil based	12	16				Superfast: Slow
11	Test14	JLLD	LIF	Oil based	12	13	3	3	30	Medium: Slow
12	Test15	JLLD	LIF	Oil based	12	13	3	3	30	Medium: Slow
13	Test16	JLL5D	LIF	Water based	12	14	3	3	35	Medium: Slow
14	Test17	JLL5D	LIF	Water based	12	13	3	3	35	Medium: Slow

TEST METHOD VALIDATION

To test the test method, resin liquid was pumped through a static mixer to fill a threaded pipe and bolt pushed into the mixture. This installation eliminated effects of the plastic film and rebar mixing. As shown in Figure 2, a JX bolt with static mixer gave relatively consistent results along the length of the pipe compared to a bolt mixing through a resin capsule. This test proved the selection of 80mm long sectioning was appropriate for the JX bolt rib spacing.

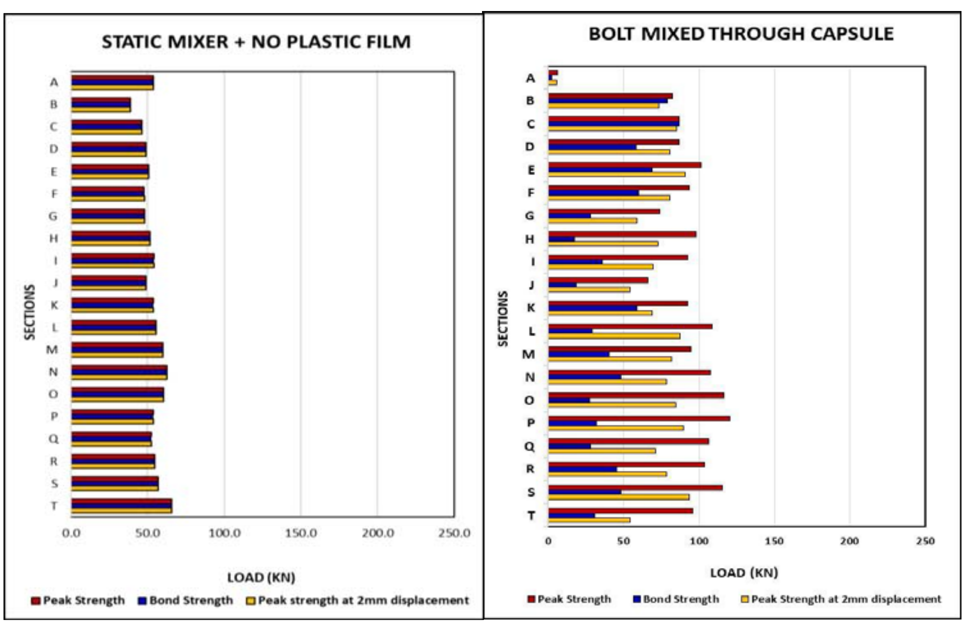

Figure *2*: Resin mixed through a static mixer and without resin capsule plastic (left); Resin mixed by ribbed rebar rotated through the resin capsule (right)

RESULTS AND DISCUSSIONS

Results from about 300 push tests were compiled to evaluate and benchmark the different types of J-Lok resins manufactured in the Australian market. These results were also used to study the effects of ribbed rebar mixing the contents of the different resin capsule designs by evaluating the variations in load transfer capacity along the length of an encapsulated bolt.

As seen in Figure 3, six main variations in the type of load vs displacement curves were derived from the push test data and these were quite inconsistent throughout the length of the bolt.

Bond strength taken when the gradient reaches 20kN/mm is a standard parameter generally used in previous papers to study the load transfer capacity of resins (Hillyer, The Influence of Installation Method and Resin Properties on Rock Bolt Performance in Underground Coal Mines, 2012). This is a key parameter specified by the British standards for determining the load transfer capacity from a short encapsulation pull test (British Standards Institution, 2007). However, as seen fromthe graphs in Figure 3, the bond strength was sensitive to the type of push test graph generated and hence its variation along the bolt length was quite significant and inconsistent. These trends variation of bond strength along the bolt length was identified by Hillyer from his studies as well. Because of the many different load-displacement curves, the selection of a single data point such as bond strength from each curve was thought not to represent the overall performance of each section. Thus, additional methods were investigated to benchmark the load transfer capacity of different resins.

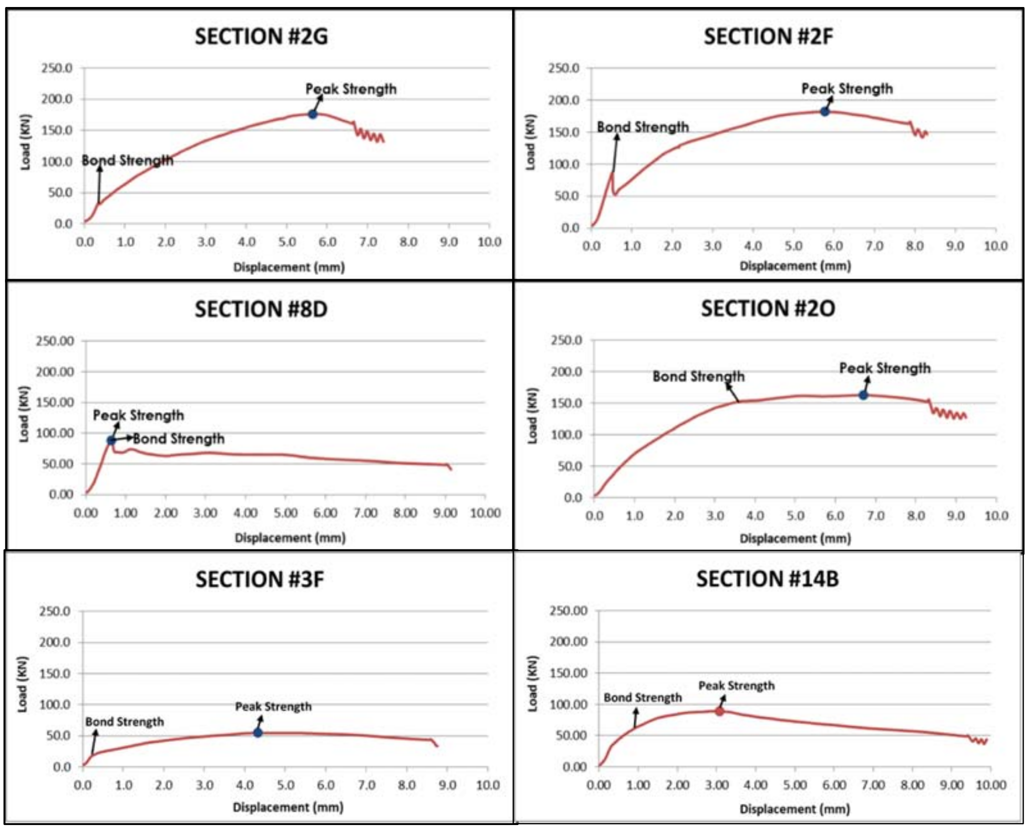

Figure 3: Variations in rate of change of load with displacement along the bolt length

Unlike bond strength, parameters that were independent of the rate of change of load transfer capacity were recorded to benchmark the mechanical performance of the different resins. Hence, the peak strength along with the area under the curve that represents the work done was evaluated. Average peak strength predicted the maximum capacity of a resin while average work done summed the optimum load capacity of the resin along with its residual strength. The average work done data was evaluated to be in agreement with the average peak load and hence it verified the validity of the benchmarking study. Table 2 and Figure 4 benchmarks the load transfer capacity for different resin types available in the Australian market.

It can be analysed from the Figure 4 that, independent of the catalyst, the grit based resin mastic resulted in the highest strength capacity whereas standard fillers resulted in the lowest strength capacity. Additionally, it was noted that oil based catalyst resulted in 30% to 40% more load transfer capacity compared to water based catalyst in case of the same resin mastic formulations.

In addition to evaluating the average load transfer capacity of the different types of resins, its variations along the length of the bolt were also evaluated to understand the effects of bolt rib mixing the resin capsule components. This is depicted in Figure 5 and Figure 6, as variations in peak strength, bond strength and work done for the different resins. It was verified that the variations along the length of the bolt was primarily an indicative of the type of resin formulations tested.

Table 2: Comparison of load transfer parameters for different types of resins

Resin Capsule ID	Average Peak Strength (kN)	Average Bond Strength (kN)	Average Work Done (J)
JL5D	90	46	677
JLL5D	99	56	747
JG5D	114	52	863
JLD	124	56	809
JLLD	125	58	910
STSA	149	66	1070
JGD	165	83	1143

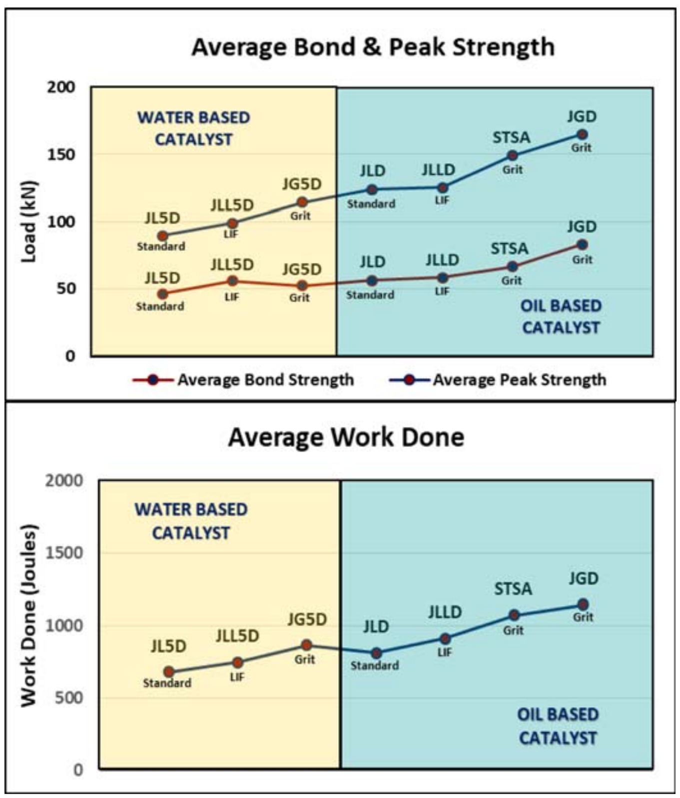

Figure 4: Benchmarking of the different J-Lok resins

Since bond strength identifies the point along the push test where the loading rate drops below 20kN/mm, it had been seen from the push tests graphs in Figure 3 that the type of load-displacement curve directly affects the bond strength value of each push test. The variations in the push test curves and hence the bond strength is analysed to be the result of the inconsistencies in the mixing of the resin mastic with the catalyst by spinning the bolt through the resin capsule. This had been verified from the test method validation method were a resin and catalyst were mixed through a Static Mixer with No Plastic Film (SMNP). As seen in Figure 5, this has resulted in minimal variations of the bond strength.

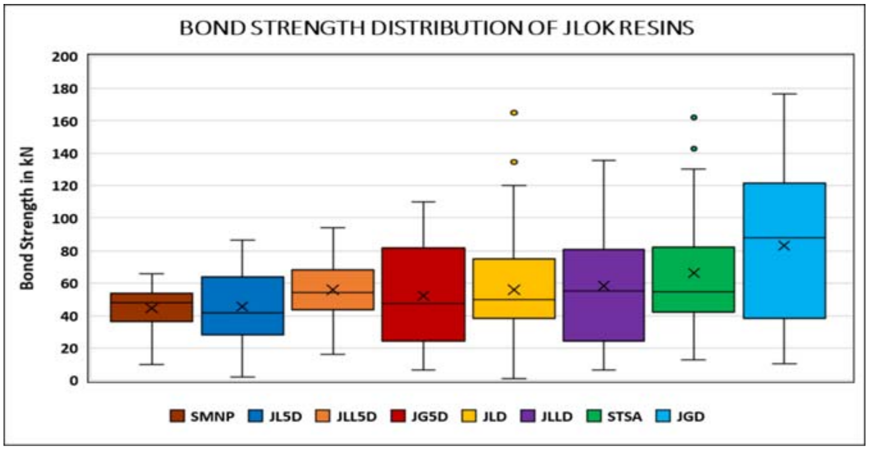

Figure 5: Box plot on bond strength distribution of different J-Lok resins

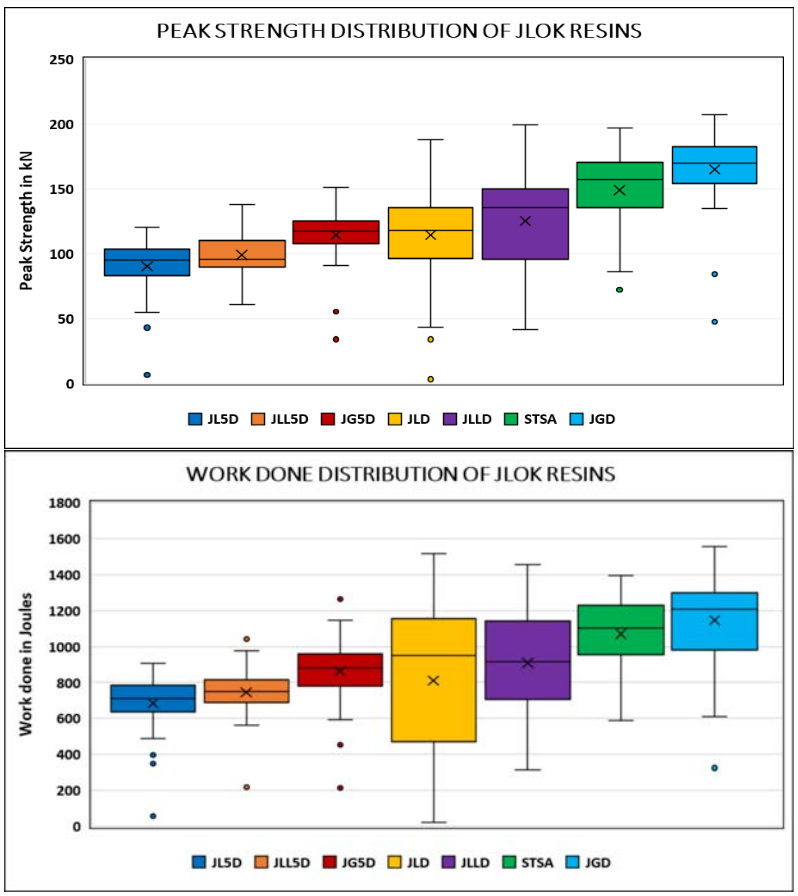

Figure 6: Box plots on peak strength and work done distribution of different J-Lok resins

From Figure 5 and Figure 6, it was noted that the average bond strength ranking of the different types of resins were mostly in alignment with the peak strength and work done ranking. Due to significant variations in bond strength, the average bond strength of a resin encapsulation was insufficient to benchmark the different types of resins. However, peak strength and work done resulted in minimal variations in its results, which gave much accurate data for benchmarking.

The variations in bond strength were quite significant irrespective of the type of resin formulation whereas the variations in peak strength and work done were more dependent on the type of resin formulation tested. To verify the correlation between the resin formulation and consistency in mixing along the bolt length, the Load Transfer Index (LTI) of each of the push test sections were evaluated based on previous studies (Thomas, 2012). LTI provides the ratio of peak load by displacement at that peak load. The data points from each tests were compiled on a scatter plot to evaluate the range of variations in LTI along the length of the bolt. Each resin formulation had a signature scatter plot of LTI data points. Higher peak strength at lower displacement gives an optimal or ideal resin performance.

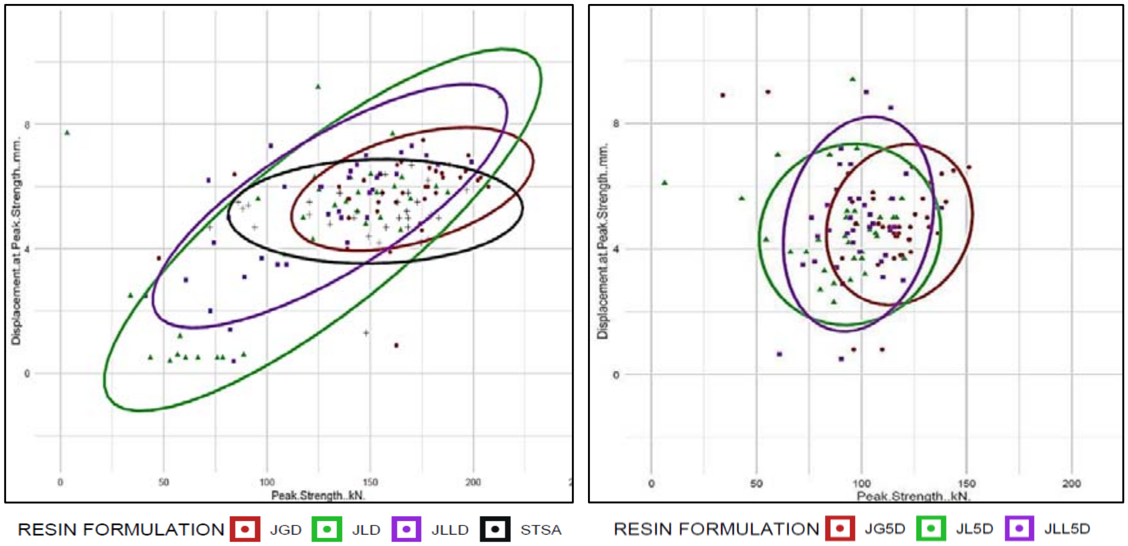

Figure 7: LTI Scatter plots - Oil based resins (left); water based resins (right)

It was verified from the LTI scatter plots and the box plots that the variations in load transfer capacity and its mean value were dependent on the type of resin capsule formulation that was installed. Primarily it was noted that though the water based catalyst had lower average strength capacity compared to oil based catalyst, it had better consistency in its load transfer variations along the bolt length. Though oil based catalyst resulted in higher variations in its load transfer capacities, grit fillers in oil-based catalyst promoted better consistency in its results.

From the above sets of results, it was analysed that grit fillers promoted better mixing of the catalyst and resin mastic. This resulted in better consistency in its load transfer capacity along the bolt length, independent of the catalyst type. Whereas standard and LIF fillers consisted of finer limestone particle size and resulted in less consistent mixing of resin mastic with the catalyst, hence the consistency in its load transfer capacity was more dependent on the type of catalyst. The smaller sized fillers induced gloving towards the top 200 mm of encapsulation in the case of standard and LIF fillers, which resulted in reduced load transfer capacities of these sections. The effects of different catalysts were also evaluated from the above results. Though oil based catalyst resulted in higher load transfer capacities, the larger catalyst to mastic ratio of a water-based catalyst resulted in more consistency along the bolt length, irrespective of the type of resin filler.

CONCLUSIONS

The J-Lok benchmarking project has developed a test method based on previous studies and research to benchmark the mechanical performance of all the J-Lok resin formulations available in Australia. The results from this project has taken into account the effects of rockbolt mixing through the resin capsule on the load transfer capacity of different resin formulations and hence it gives a more realistic benchmarking study compared to traditional laboratory mixed resin strength tests.

The bond strength of a resin encapsulation was primarily dependent on the rate of load transfer with displacement. This was evaluated to be significantly inconsistent along the bolt length in the case of a bolt rib mixing the resin capsule components. This is validated by the consistent bond strength obtained by a static mixer and no plastic film.

Different types of resins have different load transfer capacities, which were primarily influenced by the resin capsule components (limestone fillers and catalyst). Oil based catalyst had higher load transfer capacity compared to water based catalyst. In addition, independent of the catalyst, grit fillers resulted in the highest resin performance whereas standard fillers resulted in lower resin performance.

In the case of bond strength, variations along the bolt length were independent of the resin type. Whereas in the case of peak load, work done and LTI, the variations of the load transfer capacity along the bolt length was dependent on the type of resin tested. It was analysed that higher catalyst to mastic ratio volumes in the water-based catalyst resulted in better consistency of load transfer capacity compared to significant variations in most resins with oil-based catalyst. Additionally, the coarser particles of grit fillers were observed to promote better mixing and shredding of the resin capsule. This had resulted in more consistent load transfer capacity along the bolt length even in the case of an oil-based catalyst. Hence, grit based resin mastic with an oil-based catalyst, having higher catalyst to mastic ratio is expected to result in optimal resin performance. Further tests and trials on similar formulations are required to verify the optimal resin formulations.

REFERENCES

Altounyan, P, 2003. Developments in improving the standard of installation and bond strength of full column resin roofbolts, In *Proceedings 22nd International Conference on Ground Control in Mining*, Morgantwon, WV, August 6, pp. 263 - 269.

Aziz, N, Nemcik, J, Craig, P, & Hawker, R, 2014. Development of new testing procedure for the assessment of resin performance for improved encapsulated roof bolt installation in coal mines, ACARP Project Number C21011.

British Standards Institution, 2007. BS7861-1: Strata reinforcement support system components used in coal mines, pp. 36 - 42.

Emery, J, Canbulat, I, Craig, P, Naylor, J, Sykes, A, 2015. Development and implementation of the “spin to stall” resin bolting system at Anglo Americans Australian underground coal operations, In *Proceedings of the 34th International Conference on Ground Control in Mining,* WV.

Hillyer, J, 2012. The influence of installation method and resin properties on rock bolt performance in underground coal mines, Undergraduate thesis, UOW, 110p.

Hillyer, J, Craig, P, Shuqi Ma, Aziz, N, Nemcik, J and Ren, T, 2013. Variation in load transfer along the length of fully encapsulated rock bolts, based on the installation mixing parameters [online], in *Proceedings of 4th Underground Coal Operators Conference, Coal 2013, February 14-15,Wollongong*, pp137-143, (eds: N. Aziz and Kininmonth). Available from: http://ro.uow.edu.au/coal/447/

Thomas, R, 2012. The Load Transfer Properties of Post-Groutable Cable Bolts Used in the Australian Coal Industry, In *Proceedings 31st International Conference on Ground Control in Mining*, Morgantown, WV, USA, 10p.