2006

Bolt Surface Configurations and Load Transfer Mechanism

N. Aziz
University of Wollongong, naj@uow.edu.au

H. Jalaifar
University of Wollongong

J. Concalves
University of Wollongong

Publication Details

This conference paper was originally published as Aziz, N, Jalalifar, H and Concalves, J, Bolt Surface Configurations and Load Transfer Mechanism, in Aziz, N (ed), Coal 2006: Coal Operators' Conference, University of Wollongong & the Australasian Institute of Mining and Metallurgy, 2006, 236-245.

BOLT SURFACE CONFIGURATIONS AND LOAD TRANSFER MECHANISM

N Aziz[1], H Jalaifar [1, 2], J Concalves[1]

ABSTRACT: A series of laboratory based push and pull tests were carried out to investigate how surface profile influence the load transfer mechanism of bolt/resin interface. Tests were carried out in both 75 mm and 150 mm long steel sleeves. Three types of bolts were examined, they were bolts most commonly used for strata reinforcements in underground coal mines in Australia. The bolts had near equal core diameter but of different profile configurations. The change in the length of the encapsulation sleeve was examined in light of the small number of profiles encapsulated effectively in short 75 mm long sleeves. The results showed that peak loads and displacements were directly related to the height and the spacing of the bolt surface profiles. Profile spacing appears to have greater influence on load transfer capacity than the profile height.

INTRODUCTION

Rock bolting plays an important role in ground support in both civil and mining engineering. Since it was first introduced, various studies have been undertaken to gain better knowledge about how rock bolts perform in different strata conditions. These studies have incorporated both the laboratory and field tests. In laboratory test, several methods of testing have been designed to evaluate the anchorage capacity of rock bolts. The conventional short encapsulation pull test involves pulling a bolt anchored in a hole either cast in concrete or drilled in rock. As an alternative, load transfers is examined using push and pull testing of short bolts in steel sleeves in a laboratory based environment. The laboratory load transfer test removes encapsulation problems encountered in the conventional short pull tests carried out in concrete blocks or in the field.

With the recent shift from mechanical point anchors to full encapsulation cement or chemical resin anchors, an area of attention is the bolt surface profile configuration as being a relevant parameter for load transfer mechanism interaction between the bolt and encapsulation medium. Fabjanczyk and Tarrant (1992) were the early researchers that recognised the importance of bolt surface configurations in influencing the load transfer mechanism interaction between resin and bolt interfaces. However, they made no reference on profile spacing. Aziz, Dey and Indraratna (2001) examined bolt profile configurations under constant normal stiffness conditions, indicating the importance of both bolt profile height and profile spacing as important parameters influencing the load transfer mechanisms. In their later work in short encapsulations tests, Aziz and Webb (a, b) examined the load transfer characteristics of both profiled and non-profiled bolts which established the role of profile spacing in load transfer capabilities. Their initial work was conducted by push testing of bolts in 75 mm steel sleeves with hole diameters being 27 mm holes, All the bolts used were equal core diameter of 21.7 mm in diameter. Aziz (2004), Aziz and Jalalifar (2005) carried out the tests under both push and pull test conditions, and that the bolts were conducted in a centrally located with uniform resin annulus thickness. Their work included the impact of resin encapsulation thickness variations, changes of bolt profile spacing, and the three dimensional modelling of both pull and push testing.

To address the limited length of the bolts encapsulated in 75 mm steel sleeve, an additional comparative study has been undertaken using 150 mm encapsulation length, with the tests being carried out under both push and pull conditions. The details of this study form the subject of discussion in this paper, together with a limited reporting of modelling analysis of the study.

LOAD TRANSFER CAPACITY

Load is transferred from the bolt to the rock via the grout by the mechanical interlock between the surface irregularities in the interface and friction. When shearing, the load is transferred to the bolt via shear stress in the grout. The nature of bolt failure in field test is different from laboratory test. In field test, failure is dependent upon the characteristics of the system and the material properties of individual elements. Slippage may occur at

[1] *University of Wollongong*
[2] *Shahid Bahonar University of Kerman, Iran*

either of rock/grout or grout/bolt interfaces, which is called decoupling behaviour. Decoupling take place when the shear stress exceeds the strength of the interface strength. However, in the laboratory test, failure usually occurs along the bolt/grout interface. However, if real rock or concrete is used, instead of steel tube as outer casing element, then failure may happen along the rock/grout interface, depending on the strength of rock /concrete strength and hole wall profiling. Kilic A. (1999, 2002) reported that when surface friction of a borehole decrease, slippage occurs at the grout/rock interface.

In addition, when the borehole and bolt length exceeds a critical value, failure takes place at the bolt. Basically, the mechanical interlocking occurs when the irregularities move relative to each other. Surface interlock will transfer shear forces from one element to another. When the shear forces exceed the ultimate capacity of the medium, failure occurs and only frictional and interlocking resistance will control the load transfer characteristics of the bolt.

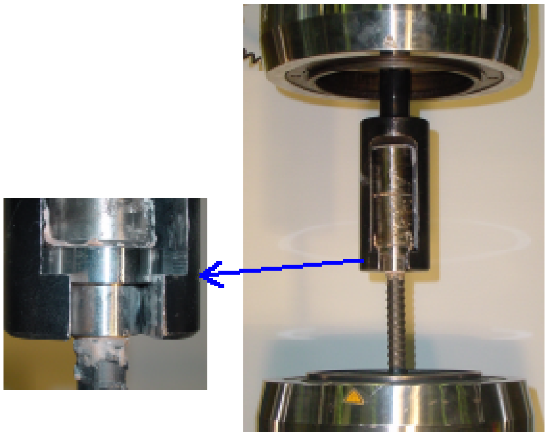
EXPERIMENTAL STUDY

Pull and push tests were carried out in two short encapsulation, 75 mm, and 150 mm length steel sleeves. Each bolt was encapsulated in the sleeve using Mix and Pour resin. As can be seen in Figure 1a the bolts were located centrally with uniform resin annulus thickness, and every effort was made to ensure the bolts were also set axially parallel to the sleeve hole axis. Figure 1b shows the general view of push test set-up in 150 mm cylinders. Because of the limited encapsulated length in 75 mm sleeve, there was insufficient number of bolt profiles embedded in resin encapsulation column, particularly for Bolt Type T3 with wider profile spacing of 25 mm. Accordingly the length of the steel sleeve was doubled by having two 75 mm selves butted at ends to form 150 mm long sleeve.

(a)

Fig. 1- (a) Uniform resin annulus thickness around the bolt (b) Push test arrangement, 150 mm sleeve

Figure 2a shows the laboratory set-up for pull test, in 150 mm cylinder. Figure 2b shows the post-test samples with the bolts being pulled out of the steel sleeves in 75 mm long, 45 mm outer diameter and 27 mm inner diameter. All failures occurred along the bolt grout interface. The grout and bolt properties are illustrated in Table 1. Tables 2 and 3 show various bolt parameters and experimental results in 75 and 150 mm encapsulation length respectively. Figures 3 and 4 show the post-test sheared bolt pushed out of steel sleeve in both 150 mm and 75 mm sleeve respectively. Figures 5 –7 show the profile of shear load–shear displacement in pull and push test in 75 and 150 mm sleeve cylinder respectively. As can be observed from both Tables 2 and 3 and in Figures 5-7, Bolt Type T3 has both push and pull loads and shear resistance values significantly higher than the other Bolt Types T1 and T2. This result is in line with previous results reported by Aziz and Jalalifar (2005). Post peak residual shear load and shear strength of the Bolt Type T3 was also higher than the other two bolts.



(a)

(b)

Fig. 2 - (a) Set up for pull test (b) Failure along the bolt grout interface in pull test

Table 1- Grout and steel properties

Parameter	Grout	Steel
UCS (MPa)	71	-
Ave. Shear strength (MPa)	16.2	645
E (GPa)	12	200
Poisson ratio	0.25	0.3

Fig.3 - Failure along the bolt grout interface in push test at 150 mm encapsulation length

(a) Steel sleeve

(b) Bolt

Fig. 4 - Post-test sheared bolt out of steel cylinder in 75 mm encapsulation length in push test

Table 2 - The laboratory results in 75 mm encapsulation length

Measured parameters	Pull			Push		
	Bolt type			Bolt type		
	T1	T2	T3	T1	T2	T3
Ave Profile Height (mm)	0.75	1.35	1.2	0.75	1.35	1.2
Ave Profile Spacing (mm)	11.0	12.0	25	11	12.0	25
Ave Max Load (kN)	114.8	131.7	160	129	139.2	172
Ave Max Displ (mm)	4.10	4.51	8.2	3.3	3.86	7.4
Ave Shear Stress Capacity (MPa)	22.2	25.4	31	24.8	26	33.2

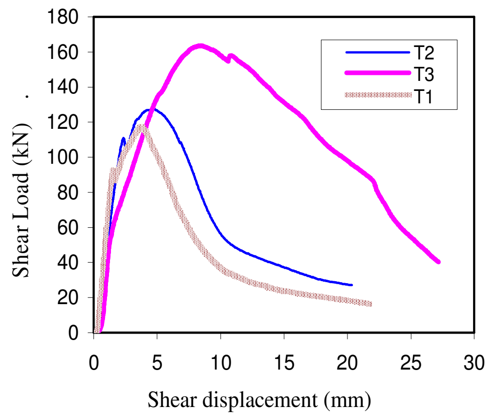


Fig.5 - Shear load as a function of displacement in pull test, 75 mm

Table 3 - The laboratory results in 150 mm encapsulation length

Measured parameters	Pull			Push		
	Bolt type			Bolt type		
	T1	T2	T3	T1	T2	T3
Ave Profile Height (mm)	1	1.35	1.2	0.75	1.35	1.2
Ave Profile Spacing (mm)	11.0	12	25.0	11.0	12.0	25
Ave Max Load (kN)	132.5	200	253.2	143	222.5	281
Ave Max Displacement (mm)	4.26	5.3	14.85	4.1	4.1	10
Ave Shear Stress Capacity (MPa)	12.78	19.5	24.42	13.8	21.5	27.1

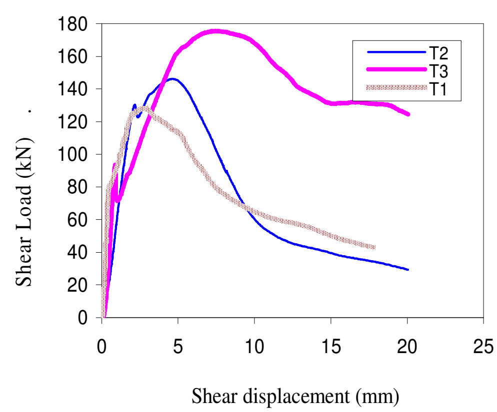


Fig. 6- Shear load as a function of displacement in push test, 75 mm

Table 4- Difference load between pull and push tests at both 75 mm and 150 mm sleeves

Bolt Type	Push load increase from 75mm to 150mm sleeve length (%)	Pull load increase from 75mm to 150mm (%)	Difference load between push and pull test at 75 mm (%)	Difference load between push and pull test at 150 mm (%)	Stiffness in 50 kN (kN/mm)	Stiffness in 100 kN (kN/mm)	Stiffness in first yield point (kN/mm)	Stiffness in peak point (kN/mm)
T1	11	15.4	11	7.6	36	34.4	-	30
T2	59	51.9	5.7	11	55	63	53	37
T3	63.6	58.2	7	10	40	39.9	28	17*

- This stiffness was calculated beyond the bolt shank yield point, so it cannot be measured as bolt stiffness.

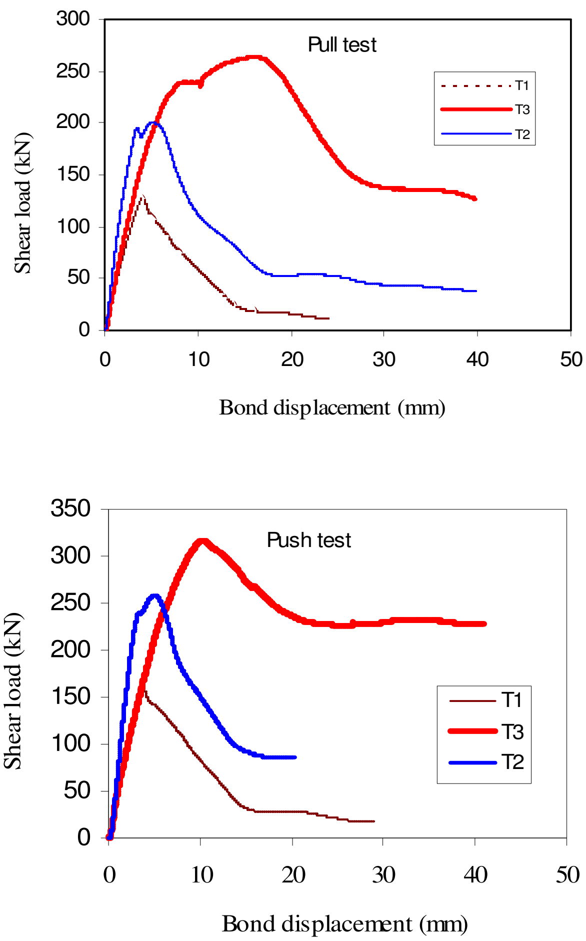


Fig. 7 - Shear load as a function of displacement in (a) pull test, (b) push test, 150 mm

Table 4 shows the difference value between the results of pull and push test in 75 and 150 mm sleeves. As can be seen from the Table 4, there is significant increase in shear load when 150 mm sleeve was used in Bolt Types T2 and T3, but not so significant in Bolt Type T1. The average difference between push and pull test, for all three Bolt Types, T1, T2 and T3 was between 7 to 11 % as deduced from Figure 8. And also it shows the shear stiffness in Bolt Type T2 is higher than other types of bolts. However, from the shear load –shear displacement trend it was found that the residual strength of the Bolt Type T3 is around 70 % of the maximum shear load in Bolt Type T2, which shows the significant effect of bolt profile spacing.

A comparison of the shear load for both pull and push tests are shown in Figure 8. Also the average shear stress values in long sleeve push test on each bolt showed a reduction of 44.2 %, 20.2 % and 18.2 % in Bolt Type T1, T2 and T3 respectively. Clearly the level of reduction in push load in Bolt Type T1 was more significant than the other two bolts.

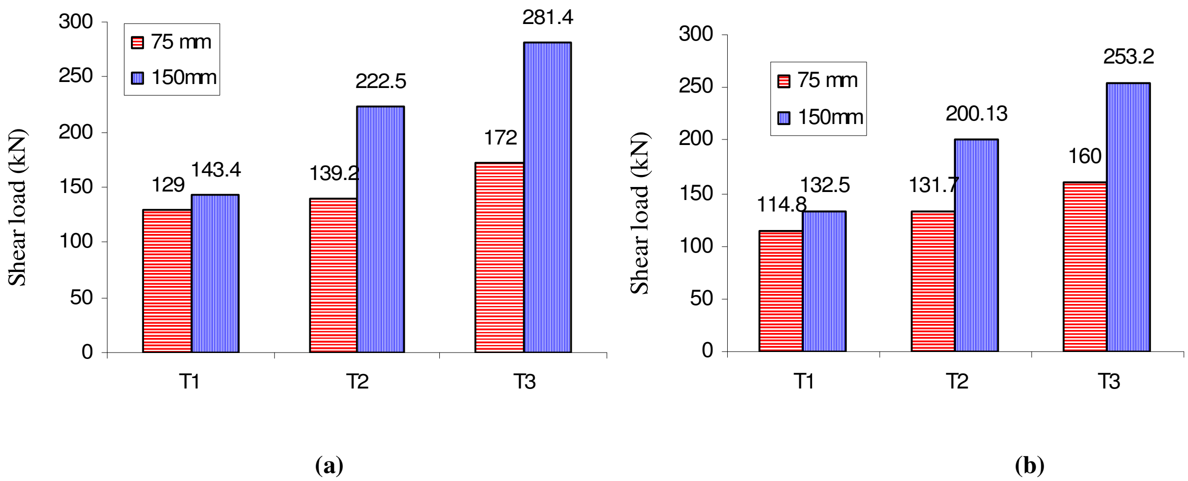


Fig. 8 - Shear load as a function of displacement in (a) push test, (b) pull test, 150 mm

This was also true for pull test in which shear stress was reduced by 42.4 % for Bolt Type T1, 23.2 for Bolt Type T2 and 21.2 % for Bolt Type T3. The reason for higher load difference in 150 mm sleeve between push and pull in Bolt Type T3 was due to fact that the shear load was greater than the steel elastic yield load of around 260 kN. This caused relatively large bolt diameter reduction and the possible loss of bond connection, eventually dropping significantly in a shear load. The effect of excessive bolt elongation and diameter loss yield would be significantly reduced with the steel sleeve length being reduced to 120 mm in length, particularly for Bolt Type T3. However, the anchorage length for Bolt Type T1 can be exceeded up to 300 mm. The peak load/shear displacement in each bolt type was different, with Bolt Type T3 was significantly higher than the other two short spaced profiled bolts. Clearly, the profile spacing appears to have a relative greater impact on the load transfer mechanism of the bolt/resin interaction than the profiles height has. This supports the earlier findings under constant normal stiffness conditions reported by Aziz (2002). Also, increased profile pacing causes greater peak load - displacement, this is advantageous as it facilitates greater rock displacement and hence improved ground control capability particularly in soft rock conditions. The mechanisms of bonding between bolt, resin and rock can be attributed more on, friction and mechanical interlock than adhesion. Its worth mentioning that bolt necking occurs at the maximum ultimate applied load level at plastic yield stage, which for these bolts is between 330 and 350 kN pull load.

NUMERICAL SIMULATION

Next, the bolt, resin and interface behaviour was simulated by 3D numerical modelling using (ANSYS 3D).

The numerical simulation of the true bolt cross-section area and its ribs were found to be difficult, as it was almost impossible with the range of softwares available in the market today. However, a serious attempt was made to model bolt profile configurations by taking into account the realistic behaviour of the rock-grout and grout-bolt interfaces, based on the laboratory observations. To achieve this task, the coordinates of all nodes for all the materials were firstly defined, then all these coordinates were inter-connected to form the elements and finally the elements were extruded, in several directions, to obtain the real shape. Finally, the numerical simulation was carried out for Bolt Type T1 in both pull and push test conditions. The relative simulation of Bolt Type T1, movement under pull test condition is shown in Figure 9. Two main fractures are produced as a result of shearing of the bolt from the resin. The first one begins at the top of the rib, with an angle of about 53 degrees running almost parallel to the rib orientation, and the second one has an angle of less than 40 degree from the bolt axis. At the fracture intersection, parts of the resin will chip away from the main resin body as it is overwhelmed by the rib surface roughness while shearing. The internal pressure produced by the bolt profile irregularities causes the tangential stress inducement in the grout. Grout fractures and shears when the induced stress exceeds the shearing strength of the grout material, thus allowing the bolt to slide easily along the sheared and slickenside fractures grout interface surfaces. The maximum bolt deflection occurs on the pulling side of the bolt, causing a reduction in bolt diameter.

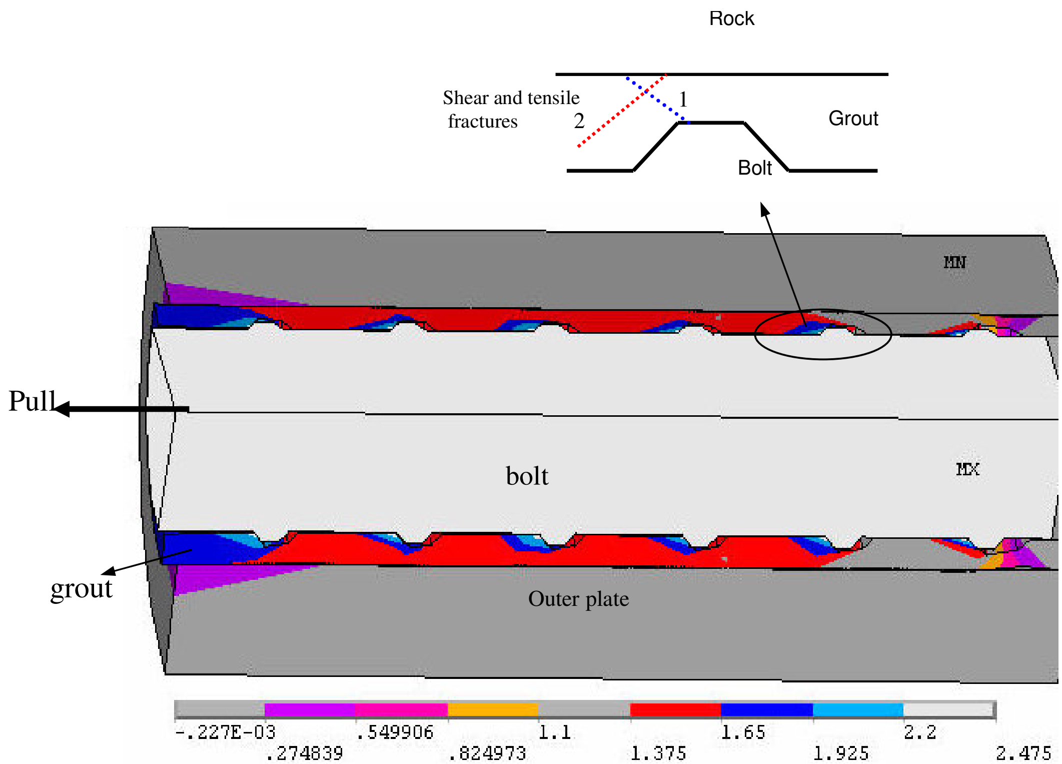


Fig. 9 - The bolt movement in pulling test

Figure 10 shows the Von Mises stress trend along the bolt profile, which shows the maximum stress being concentrated at the pulling point of the bolt, gradually reducing towards its free end. Also it shows the shear and tensile stress trend along the bolt. The maximum tensile stress along the bolt is 330 MPa, which is almost equal to one half of the elastic yield point strength of 600 MPa. This means the bolt is unlikely to reach the yield situation and necking. Figure 10 also shows that there is low level of shear stress along the bolt.

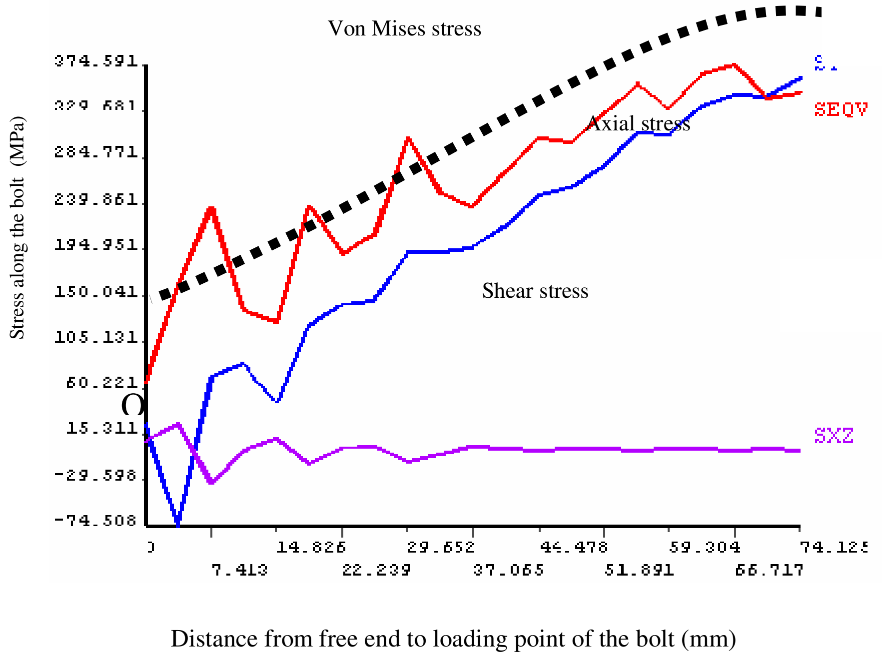


Fig. 10 - Von Mises Stress and shear stress along the bolt

CONCLUSION

Both the experimental and numerical results have lead to the following conclusions:

- The average shear stress capacity of a bolt in a push test is greater than in a pull test.
- Yielding and necking is unlikely to occur in bolts tested in 75 mm long steel sleeves as the peak shear load was around 40 % of the maximum tensile strength of the steel. However, excessive bolt yielding and diameter reduction is likely to occurs in 150 mm in Bolt Type T3 as the pull load is greater than the peak elastic yield load. Necking occurs at the maximum ultimate applied load level at plastic yield stage, which for these bolts is between 330 and 350 kN pull load.
- Bolt-resin interface failure occurred by initially shearing of the grout at the profile tip in contact with the resin. The load failure of the resin /bolt surface contact is dependent on the profile height as well as spacing.
- Increased profile pacing causes greater peak load - displacement, this is advantageous as it facilitates greater rock displacement and hence improved ground control capability particularly in soft rock conditions.
- Bolt Type T3 produced higher shear resistance, followed by Bolt Type T2 and then T1.
- Post peak load displacement profile of Bolt Type T3 is greater than the other Bolt Types T1 and T3 respectively.
- The length of steel sleeves used for load transfer mechanism study should facilitate a sufficient number of profiles encapsulation and in parity with the profile spacing of the bolt tests. Particular care must be taken to ensure the bolts installed centrally located in the sleeve and with the uniform resin annulus thickness.
- Bolt- resin interface failure occurred by initially shearing of the grout at the profile tip in contact with the resin.
- Numerical simulation provided an opportunity of better understanding of stresses and strains generated as a result of bolt resin interface shearing.

REFERENCES

Aziz, N, (2002). A new technique to determine the load transfer capacity of resin anchored bolts. 3rd Australian Coal Operators Conference, Wollongong, pp.176-185.

Aziz, N. (2004). Bolt surface profiles- an important parameter in load transfer capacity appraisal. Proceedings of the fifth International conference on ground control and mining construction, September, Perth, pp221-230.

Aziz, N I, Dey, D and Indraratna, B, 2001, New approach to study load transfer mechanisms of fully grouted bolts, Proceedings of 17th International Mining Congress and exhibition in Turkey, The Chamber of Mining Engineers of turkey, Ankara, June 19-22, pp143-154

Aziz, N and Jalalifar, H, 2005. Investigation into the transfer mechanism of loads in grouted bolts. Australian Geomechanics Journal. Vol. 40,No.2. 99-113.

Aziz, N and Web, 2003a. Load transfer Appraisal of bolts using short encapsulation push test. 4th Underground Coal Operators, Conference. Wollongong. pp. 72-81.

Aziz, N and Web, B, 2003b, Study of load transfer capacity of bolt using short encapsulation push test., 22nd International Conference on ground Controlin Mining, Morgantown, WV, August 5 -7, pp203-207.

Fabjanczyk, M. W. and Tarrant, G. C. (1992), Load transfer mechanisms in reinforcing tendons, International conference on ground control in mining, Wollongong University, pp.212-218

Kilic A M, 1999. The effects of grout properties to the bolt capacity, Proceedings of the sixteenth Mining Congress of Turkey, Ankara, Kozan press, 189-196.

Kilic, A, Yasar, E and Atis, C D, 2002, Effect of bar shape on the pull out capacity of fully grouted rock bolts, Tunneling & Underground Space T