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Study of Load Transfer Capacity of Bolts Using Short Encapsulation Push Test

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ABSTRACT: A series of laboratory experiments were conducted on a variety of bolt types to examine the load transfer capacities of different profiled bolts in short encapsulation push testing. A 70 mm .section of 150 mm long bolt specimen was anchored in a 70 mm long stainless steel tube using full resin encapsulation. Six types of different profiled bolts and two non - profiled bolts were tested. Bolts with higher profile were in general found to have greater shearing resistance and higher stiffness than low profile holts. Widely spaced profiles allow greater displacement at peak shear strength, and bolts with no profiles produced very little load transfer usability. Rough surfaced plain bolts showed a significant load transfer capability in comparison to a factory supplied smooth surface bolt which supports the belief that rusted bolts have higher load transfer capability that un-rusted bolt surfaces.

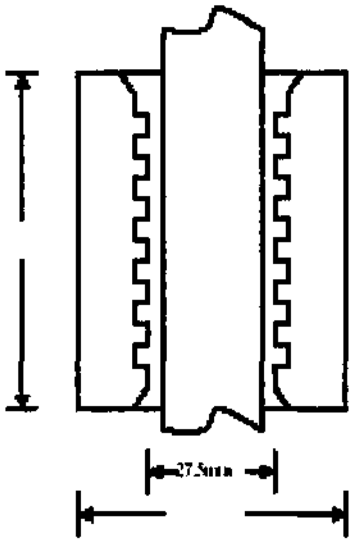
1 INTRODUCTION

In the third Australian Coal Operators Conference, Coal 2002 (Aziz. 2002) discussed the load transfer capacity of bolt surface profile under Constant Normal Stiffness conditions (CNS). The main findings from the study were that bolts with deeper rib profiles offered higher shear resistance at low normal stress conditions while bolts with closer rib spacing offered higher shear resistance at high normal shear stress conditions. Also it was found that the peak shear stress occurred at 60 % of the profile spacing. In continuation of the work on the subject a number of studies were undertaken to examine the load transfer capacities of different profiled bolts using three different approaches. One such method involves the use of the Short Encapsulation Push Test. Unlike the tests under CNS conditions, the short encapsulation test is carried out under Constant Normal Load conditions (CNL) provided by the walls of the steel cylinder.

Questions are often asked as to why some bolts have higher and wider spaced profiles while others have shallow and narrow spaced profiles and how does each type react in different ground conditions? The an.swer to this question depcnd.s upon the method of testing. The most common methods used, such, as the short encapsulation pull test have no way of identifying scientifically the role of profile configuration on the load transfer characteristics of the bolt. The conventional short encapsulation test tends to suffer from a variety of operational and inherent defects, which make it difficult to produce repeatable results. Also, the short encapsulation pull test is conducted under CNL condition which generally ignore the changing nature of the confining load due to relative resin /bolt surface displacement. The only effective method of characterising the bolt profile influence is to conduct the tests under CNS conditions. Short encapsulation push test can be considered as a suitable method to examine the influence of profile configuration on load transfer capacity as the technique can be used under a controlled environment which can overcome many of the well known problems associated with the conventional short encapsulation pull testing method, even though the method embraces the principle of CNL conditions.

2 SHORT ENCAPSULATION PUSH TESTING

Figure 1 shows the details of the Short Encapsulation Test Cell. The cell is 75 mm long, which is 50% greater than that reported by Fabjanczyk and Tarrant(1992). The longer length cell was selected in order to permit a sufficient number of bolt surface profiles to be encapsulated in the cell. The cell consists of a machined steel cylinder with an internal groove. The groove provides grip for the encapsulation medium and prevents premature failure on the cylinder / resin interface. As opposed to pull testing, push testing involves the pushing the bolt under constant normal load conditions thıough the hardened resin. With the use ot a digital load cell and extensometer, a full load / displacement history could be obtained. A total ot 20 cells were prepared for the study.



Figuıe I. Push test cell

3 ROCK BOLT SAMPLE PREPARATION

Six types ot profiled bolts and two versions of plain surface bolts were selected for the study. The first four types of the profiled bolts are Australian manufactured and widely used in Australian mines. The other two profiled types included an overseas bolt and a locally developed new bolt, yet to be marketed in Australia. The surface bolts consisted of a factory supplied bolt which was not yet profiled and a profiled bolt whose profiles were machined off in the laboratory. Table 1 shows the details of each tested bolt. For wider application in Australian mining industry, the first four bolts, namely Bolt Types Tl to T4 were called popular bolts, and the rest consisted of two profiled bolts and two plain surface bolts identified as additional bolts. For obvious reasons all the bolt types were given identification designations.

The rock bolt samples were each cut to lengths of 120mm using a mechanised saw. The equal lengths ensured that all the samples of the same type had an equivalent number of profile ribs and that the ends of each sample were square. All bolts were encapsulated into the push test cells using Fosroc PBl Mix and Pour resin grout. The uniaxial compressive strength and shear strength of the resin used for the tests were in the order of 70 MPa and 16 MPa respectively. The encapsulated samples were allowed to harden for a minimum of seven days before being tested.

The general arrangement for testing is shown in Figure 2. Information on the load/displacement was monitored on a PC, connected to a Load call and an LVDT of the loading system via a data logger.

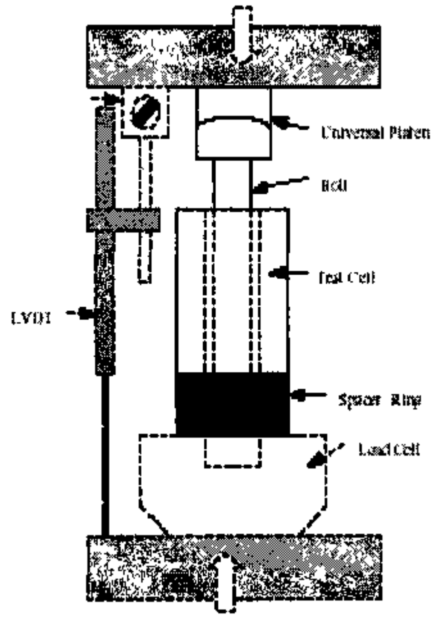


Figure 2. Instrumented push test arrangement

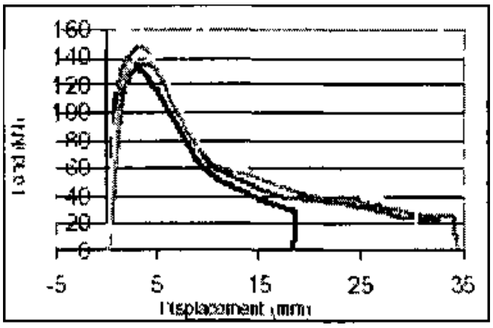
4 RESULTS AND DISCUSSION

4.1 Load - displacement relationship

Figure 3 shows typical load displacement graphs of testing Type T2 bolts. The figure shows the results of four tests, and demonstrates the repeatability of the tests with a reasonable degree of confidence. Figure 4 shows the combined load displacement graphs of a group of four popular profiled bolts. Clearly, there are differences in the graphs of different bolts and one notable example is that of Bolt Type T3. This bolt had widely spaced profiles, and the peak load occurred at greater displacement than the rest of the bolts. Table 2 shows the details of the test results for the entire profiled and plain surface bolts. These results are the average values for the maximum load, shear strength, and bolt resin interface stiffness values.

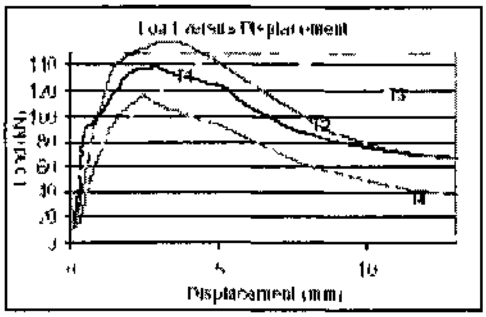
Table 1 Rockbolt specifications

TYPE	T1	T2	T3	T4	T5	T6	S1 (Rough)	S2 (Smooth)
Profile centres	12.00mm	12.00mm	25.00mm	12.00mm	12.0mm	8.0mm	--	--
Profile height	1.00mm	1.60mm	0.80mm	1.50mm	1.24mm	1.5mm	<0.1mm	1.6mm
Profile angle	22.5^0	22.5^0	22.5^0	19^0	4.8^0	8.8^0	--	--
Profile top width	1.50mm	2.00mm	2.50mm	1.80mm	1.6mm	2.0mm	--	--
Profile base width	3.00mm	3.50mm	5.00mm	3.70mm	3.8mm	3.5mm	--	--
Samples								



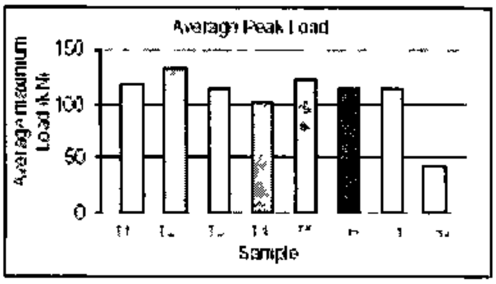
fiğine 3 Load versus displacement values ot Bolt T2

The peak load - displacement peiloiinani.es ol valions bolls aie picsented in Fıgıııe 5 The highest ıveıage peak load ol 1 32 56 kN was that ot Bolt Tvpe T2 This was 23% gıeateı than that achieved bv the Bolt Type T4 at 102 09 kN The ditteience between these two extreme values is attributed to the holt pıolıle heights

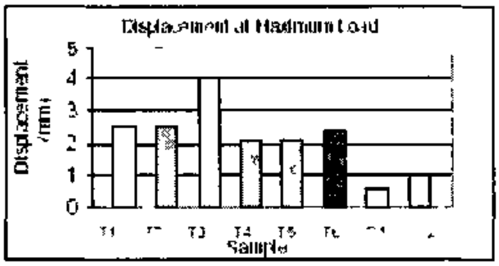


FILUIC 4 Load Displacement gıaphs ot fouı pıolıles bolts

Ex miination ol the a\erage displacement lesults achieved by the bolt samples In Figure 6 showed that Bolt Type T3 achieved the highest displacement 01 4 03mm Bolt Type T2 followed this with 2 54mm Bolt Type T4 achieved the lowest aveiage displacement with 2 05mm ot displacement Ot the additional bolts tested it was found that the Bolt Tvpe T6 sustained a displacement ol 2 37 mm at maximum load while the newly developed Bolt T\peT5 achieved a displacement ot 2 019mm Rough surfaced Bolt TypeSI achieved 1 01 mm while smooth sulfated Bolt Type S2 athicved 0 57mm ot displacement at maximum load A compaialive study lepoited by A/17 Indiaratna and Dey (1999) and A/i/ (2002) between Bolt Types Tl and T3 and tested undeı CNS conditions has indicated that Bolt Types Tl and T3 gave similar compuitivc displacement patterns but at gıeateı displacement langes It is thus leasonable to suggest that wideı pıolıle bolts can accommodate gıeateı peak load displacement than bolts with closely spaced pıotıles This ıs consıdeıed as an advantage Î01 Bolt TypeT3 lll accommodating 11101 e gıound displacement without losing its load lianslei capability



Fıgııe 5 Average peak load ot all the bolts



Fıguıe 6 Displacement at peak load ot all holts

4 2 Sluai Suenqth Caput H

The average shcai stiength capacities achieved by each bolt t>pe are lepiesented below in Figure 7 It was lound that Bolt Type T2 had the highest shear stiength capacity ol 25 89 MPa Bolt Type Tl with an aveiage sheai stiength ol 22 88 MPa was 11 63% less then Boll Type T2 The lowest shear stiength value ol the populai bolt lype was Bolt Type T4 at 19 88 MPa which was 23 21% less then the shcai stiength value ot Boll Type T2

The lough sulfated plain bolt achieved a sheai strength capacity ot 22 35 MPa and the smooth plain suitace bolt achieved 7 71MPa, which was a laige diop in the shear stiength values with ıespect to mugh sui faced plain boll Bolt Type T5 achieved 25 17 MPa which was tiactionally less than Bolt Type T2 while the oveiscas manutactuied Bolt Type T6 with 21 76 MPa achieved a sheai stiength capacity 15 95% less then Bolt Type T2

Table 2 Push test chaiacteiistics ot different bolts - Average values

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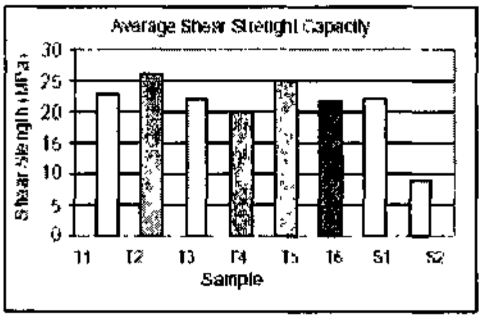


Figtue 7 Average shear strength capacity

4.3 System Stiffness

The system stiffness is the gradient of the maximum load sustained by a bolt to the displacement at the maximum load of a fully encapsulated bolt. Expressed in kN/mm the average system stiffness for each bolt type is shown lll Table 2. It is interesting to note that both smooth surfaced bolts were suffer than the protiled bolls, however this does not mean that the plain surfaced bolts have greater load transfer capacity as the displacement at peak load was very minimal.

5 LOAD TRANSFER AND PROFILE DESIGN

5 *I Bolt Surface / Resin Interaction*

Almost all the load transfer capacity between encapsulation resin and the boll can be accepted as being attributed to the frictional effect. The level of the frictional force is dependent upon the confining pressuie. The magnitude of the changes in peak shear strength with respect to applied normal load is shown Figure 8. The graph indicates that there is an insignificant degree of cohesion bonding between the bolt surface and the resin when the vertical load approaches zero. Figure 9 demonstrates the separation of the resin from a bolt when the cast resin was sawed axially and both halves of the resin shell came off clean from the bolt. In summary the load transfer capacity of the resin /bolt interface is a function of the applied normal load alone.

5.2 Profile Spacing

Examination of the average bolt profile spacings, outlined in Table 1, found that Bolt Type T3 had the greatest profile spacing with 25mm between profile centres. Bolt Type T2 had a profile spacing approximately half that of Bolt Type T3 with 12mm, while both Bolt Type Tl and Boll Type T4 had spacings of 11 mm. The latter product had a design that is called an overlapped design that produced a general reduction in the effective shearing surface of the bolt. Bolt Type T3 design produced a bolt with a reduced circumferential profile length resulting from the absence of a central spine or 'Hash'. As can be seen from Figure 4, it was evident that the displacement required lor Bolt Type T3, to achieve maximum load, was approximately 53% greater than (he displacement of Bolt Type Tl and Bolt Type T4 whereas Bolt Type T2 had a peak load displacement of approximately 40%. From this it was evident that an increase in profile .spacing has resulted in an increase in the displacement at maximum peak load.

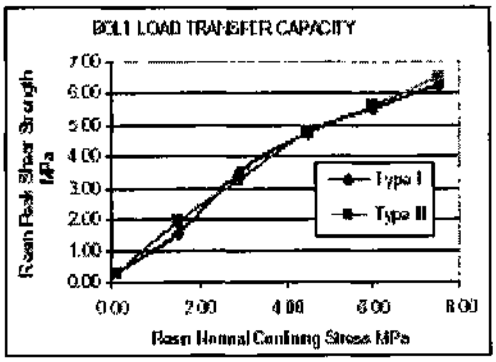
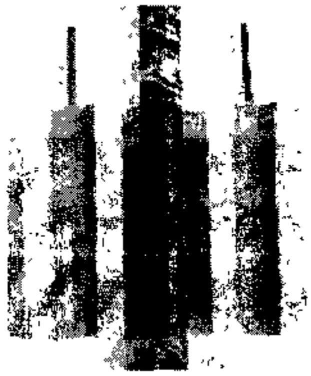


Figure 8 Resin/Bolt load shear strength under various normal confining pressures

The ıncıcased displacement required to achieve maximum load resulted in a lower system stiffness of the bolt type.



Figuie 9 Resin bolt separation after bolt encapsulation

5.3 Profile Height

Testing ol Bolt Types T3 and Tl were used to examine the effect of profile height on the shear strength capacity across the bolt resin interface. Bolt TypesTl and T3 were of the same "T'Bolt design, possessing similar profile spacings, but had different profile heights. As outlined in Table 1 Bolt Type T3 had a profile height of 1.4mm, while Tl had a height of 0.8mm. However, both Bolt Types T3 and Tl achieved shear strength capacities of 22.33 Mpa and 22.88MPa respectively. Bolt Type T2 achieved a greater shear strength capacity compared to Bolt Type T1. These results are reflected in Figure 6, which represents typical load displacement performances of Bolt Type Tl and Bolt Type T2 respectively.

5.4 Bolt Surface Condition

The load displacement shown in Figure 7 clearly indicates that the increase in roughness of the plain surface of the bolt has greatly influenced the shear strength capacity of the bolt. The rough finish of the bolt surface allowed additional grip to be provided between the bolt and resin inteiface and this reinforces the belief thai rusted bolts have greater load transfer capability than a clean bolt of the same type.

6 PRE AND POST FAILURE BEHAVIOUR

Pre and post failure curves obtained for all the profiled bolt types show that, common to all the bolts tested, the average displacement at peak load occuired at approximately 34?? of the profile spacing as shown in Figure 4. The peak load displacement of 34% is almost 50% of the values obtained by Aziz (2002), when examining the load transfer of Bolt Types Tl and T 3 bolts under Constant Normal Stiffness condition and that clearly demonstrates the influence of test technique on the result outcome.

The post peak load displacement graphs also depicted durèrent picture for Bolt Type T3 in comparison to the rest of profiled bolts. It showed that the post peak load / displacement profile was higher than the other bolts, indicating the ability of the bolt to maintain greater load transfer capability than others.

7 CONCLUSIONS

Realistically the application of the Short Encapsulation Push Test technique in evaluating load transfer capability of profiled bolts cannot be accepted as a scientifically recognised creditable technique, as the test is carried out under constant normal load conditions, which is not the case. The profiled bolt surfaced are not smooth, and thus the movement of profiles relative to resin surface would inevitably lead to changes in the vertical load. The application of the system on plain surface bolts is however valid. Nevertheless, the Load transfer capacity assessment is, to a certain extent, warranted because the method overcomes many of the problems associated with the conventional pull testing method, including the effect of resin gloving, host material failure and bolt yield. The test cell provided a standardized environment that allowed testing to focus on profile design only. The tests showed that:

- Rib profile height influenced the shear strength capacity of a bolt.
- Peak shear load occurred on all profiled bolts at displacements equivalent to 34%J of the rib
- spacing, which is almost 50 % of the values obtained from testing under CNS conditions.
- Load transfer capacity between encapsulation resin and the bolt is due almost entirely to the frictional affect.
- The rough finish of the bolt surface permits additional grip between the bolt and resin interface and this enforces the belief that rusted bolt surfaces have greater load transfer capability than clean surface bolt.

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