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STUDY OF LOAD TRANSFER CAPACITY OF BOLTS USING SHORT ENCAPSULATION PUSH TEST

Naj Aziz [1] and Benjamin Webb [1]

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 bolts. Widely spaced profiles allow greater displacement at peak shear strength, and bolts with no profiles produced very little load transfer capability. 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.

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 answer to this question depends 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.

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 through the hardened resin. With the use of a digital load cell and extensometer, a full load / displacement history could be obtained. A total of 20 cells were prepared for the study.

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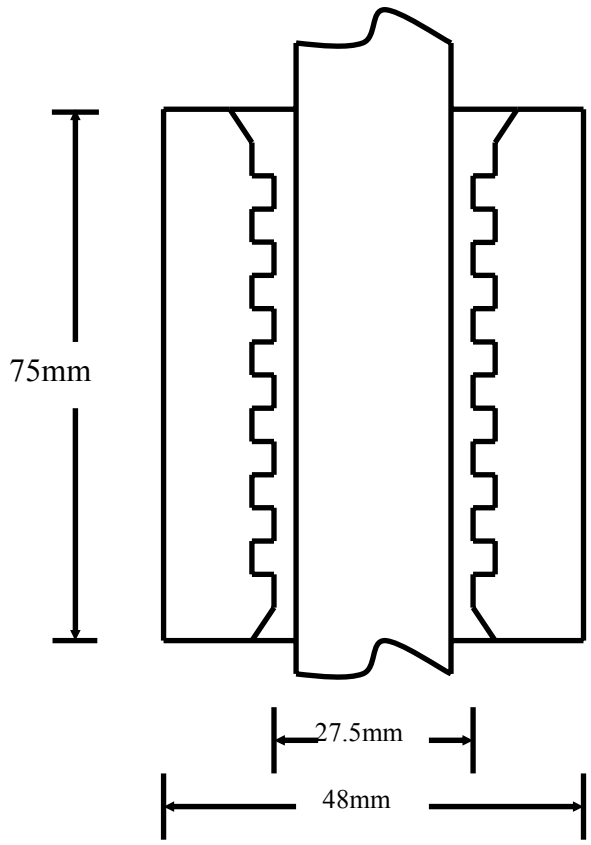

FIG. 1 - Push test cell

ROCK BOLT SAMPLE PREPARATION

Six types of 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 T1 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 PB1 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.

FIG.2a - Short Encapsulation test arrangement in a compression machine

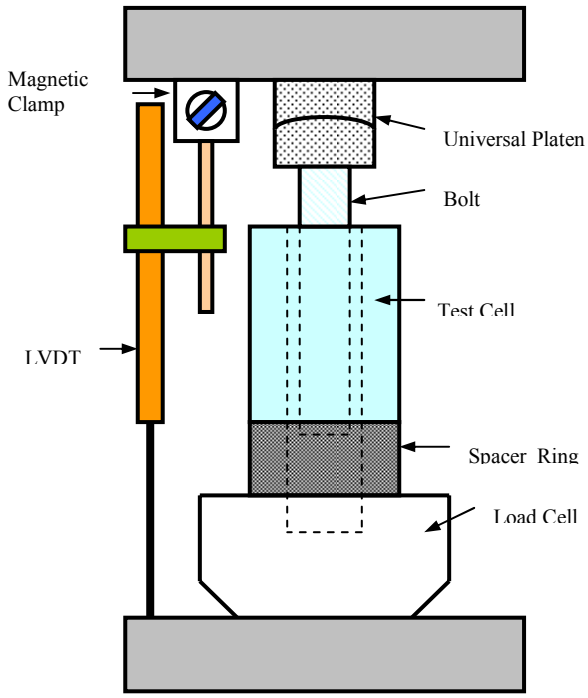

FIG. 2b - Instrumented push tests arrangement

RESULTS AND DISCUSSION

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 - Rock Bolt Specifications

TYPE	T1	T2	T3	T4	T5	T6	S1 (Rough)	S2 (Smooth)
Profile type	T-Bar	T-Bar	T-Bar	J-Bar	Thread Bar	Thread Bar	Filed (T-Bar)	None
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^{o}	22.5^{o}	22.5^{o}	19°	4.8^{o}	8.8^{o}	--	--
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								

Table 2 Push test characteristics of different bolts – Average values

SAMPLE TYPE	Popular				Additional			
Bolt Type	**T1**	**T2**	**T3**	T4	**T5**	**T6**	**S1 Smooth**	**S2 Rough**
Ave Profile Height (mm)	0.70	1.40	1.20	0.70	1.24	1.12	--	--
Ave Profile Spacing (mm)	11.00	12.00	25.00	11.00	12.00	3.00	--	--
Ave Max Load (kN)	117.12	132.56	115.11	102.09	121.32	112.79	43.59	113.64
Ave Max Displacement (mm)	2.51	2.54	4.03	2.05	2.09	2.37	0.57	1.01
Ave Shear Stress Capacity (MPa)	22.88	25.89	22.33	19.88	25.00	21.79	8.58	22.35
Average System Stiffness (kN/mm)	46.72	52.27	28.59	49.75	57.94	47.59	76.47	112.40

The peak load – displacement performances of various bolts are presented in Figure 5. The highest average peak load of 132.56 kN was that of Bolt Type T2. This was 23% greater than that achieved by the Bolt Type T4 at 102.09 kN. The difference between these two extreme values is attributed to the bolt profile heights.

Examination of the average displacement results achieved by the bolt samples In Figure 6 showed that Bolt Type T3 achieved the highest displacement of 4.03mm. Bolt Type T2 followed this, with 2.54mm. Bolt Type T4 achieved the lowest average displacement with 2.05mm of displacement. Of the additional bolts tested, it was found that the Bolt Type T6 sustained a displacement of 2.37 mm at maximum load, while the newly developed Bolt TypeT5 achieved a displacement of 2.019mm. Rough surfaced Bolt TypeS1 achieved 1.01mm, while smooth surfaced Bolt Type S2 achieved 0.57mm of displacement at maximum load. A comparative study reported by Aziz, Indraratna and Dey (1999) and Aziz (2002) between Bolt Types T1 and T3 and tested under CNS conditions has indicated that Bolt Types T1 and T3 gave similar comparative displacement patterns but at greater displacement ranges. It is thus reasonable to suggest that wider profile bolts can accommodate greater peak load displacement than bolts with closely spaced profiles. This is considered as an advantage for Bolt TypeT3 in accommodating more ground displacement without losing its load transfer capability.

Shear Strength Capacity

The average shear strength capacities achieved by each bolt type are represented below in Figure 7. It was found that Bolt Type T2 had the highest shear strength capacity of 25.89 MPa. Bolt Type T1 with an average shear strength of 22.88 MPa was 11.63% less then Bolt Type T2. The lowest shear strength value of the popular bolt type was Bolt Type T4 at 19.88 MPa, which was 23.21% less then the shear strength value of Bolt Type T2.

The rough surfaced plain bolt achieved a shear strength capacity of 22.35 MPa, and the smooth plain surface bolt achieved 7.71MPa, which was a large drop in the shear strength values with respect to rough surfaced plain bolt. Bolt Type T5 achieved 25.17 MPa, which was fractionally less than Bolt Type T2, while the overseas manufactured Bolt Type T6 with 21.76 MPa achieved a shear strength capacity 15.95% less then Bolt Type T2.

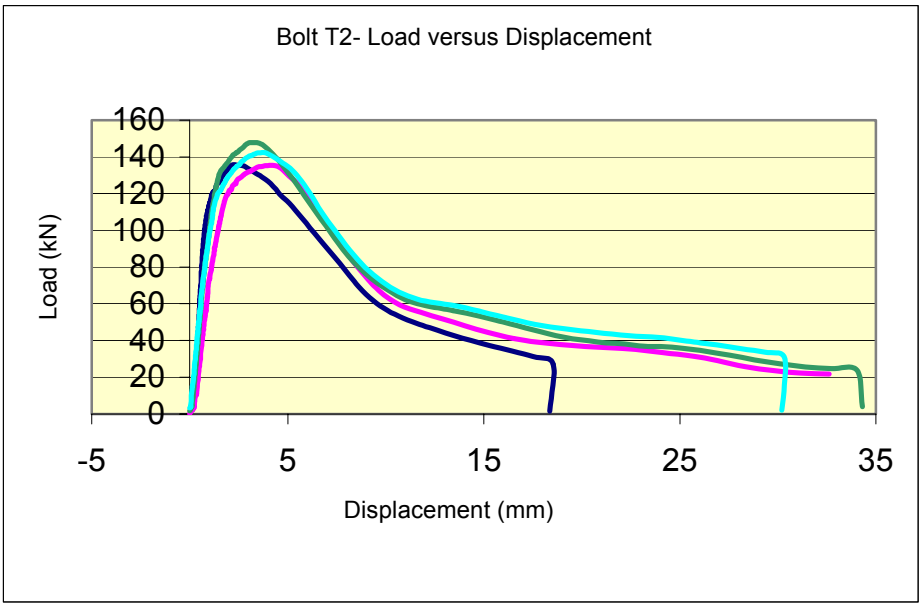

Fig 3 – Load versus displacement values of Bolt T2

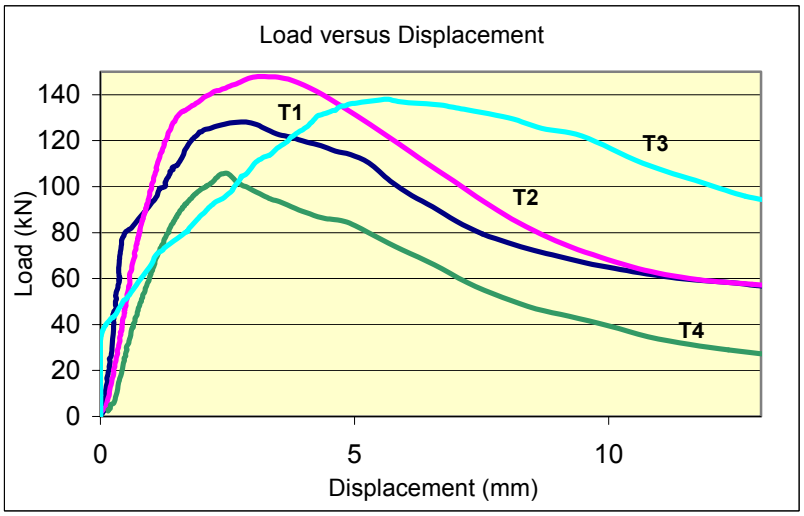

FIG. 4- load displacement profiles of four popular profiled bolts

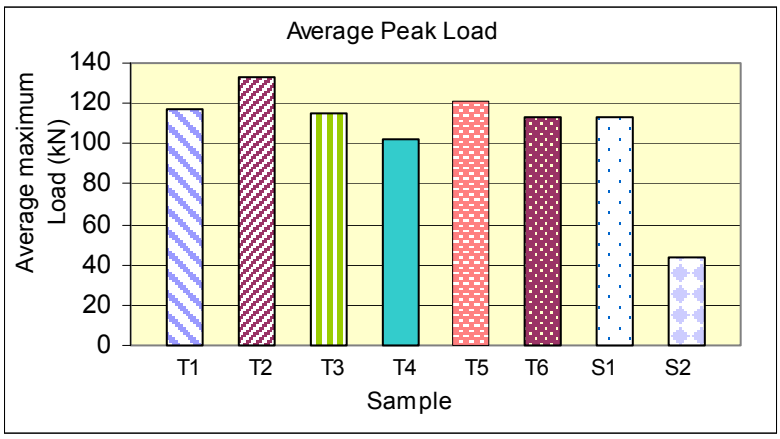

FIG. 5 - Average peak load of all the bolts

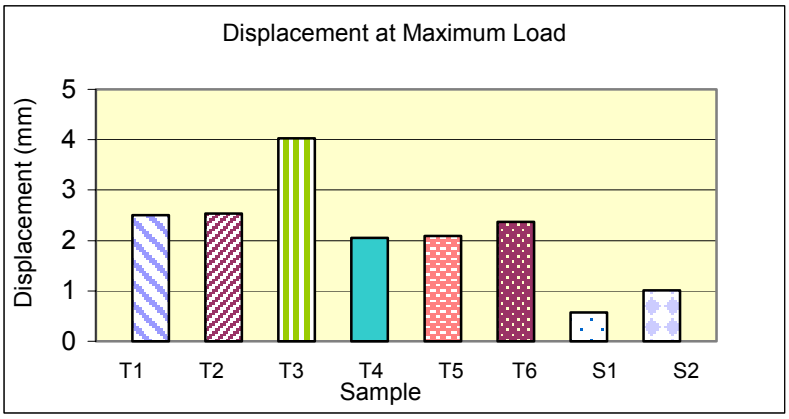

FIG. 6 - Displacement at peak load of all bolts

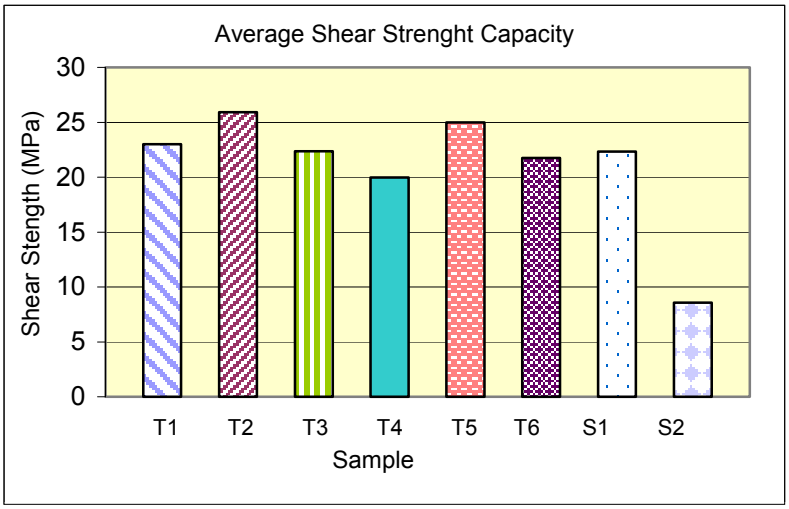

FIG. 7 - Average shear strength capacity

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 in Table 2. It is interesting to note that both smooth surfaced bolts were stiffer than the profiled bolts, however this does not mean that the plain surfaced bolts have greater load transfer capacity as the displacement at peak load was very minimal.

LOAD TRANSFER AND PROFILE DESIGN

Bolt Surface / Resin Interaction

Almost all the load transfer capacity between encapsulation resin and the bolt can be accepted as being attributed to the frictional effect. The level of the frictional force is dependent upon the confining pressure. 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.

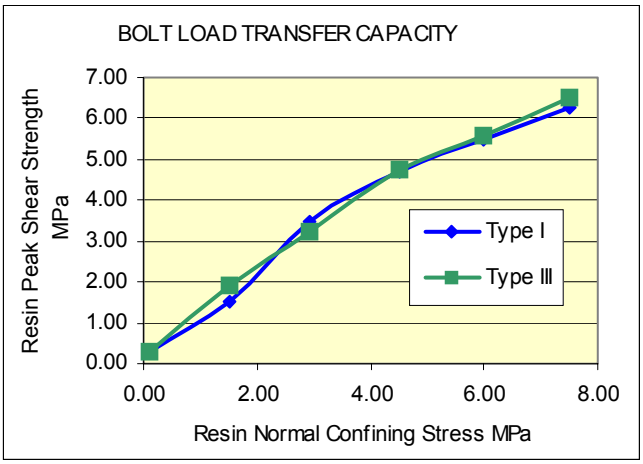

FIG. 8 - Resin /Bolt load shear strength under Various normal confining pressures

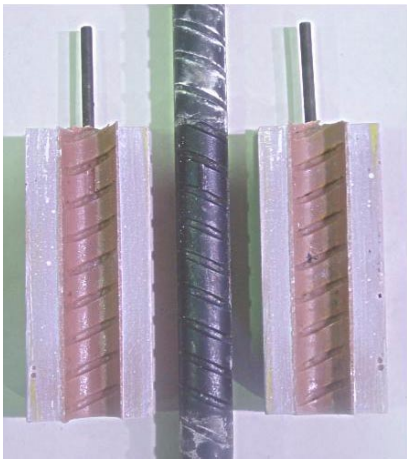

FIG. 9 - Resin bolt separation after Post encapsulation

Profile Spacing

Examination of the average bolt profile spacings, outline 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 T1 and Bolt Type T4 had spacings of 11mm. 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 'flash'. As can be seen from Figure 4, it was evident that the displacement required for Bolt Type T3, to achieve maximum load, was approximately 53% greater than the displacement of Bolt Type T1 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. The increased displacement required to achieve maximum load resulted in a lower system stiffness of the bolt type.

Profile Height

Testing of Bolt Types T3 and T1 were used to examine the effect of profile height on the shear strength capacity across the bolt resin interface. Bolt TypesT1 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 T1 had a height of 0.8mm. However, both Bolt Types T3 and T1 achieved shear strength capacities of 25.89 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 T1 and Bolt Type T2 respectively.

Bolt Surface Condition

The load displacement shown in Figure 5 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 interface and this reinforces the belief that rusted bolts have greater load transfer capability than a clean bolt of the same type.

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 occurred 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 T1 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 different 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 that others.

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% 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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