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DEVELOPMENT OF NEW TESTING PROCEDURE FOR THE ASSESSMENT OF RESIN PERFORMANCE FOR IMPROVED ENCAPSULATED ROOF BOLT INSTALLATION IN COAL MINES

END OF PROJECT REPORT

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# Table of Content

EXECUTIVE SUMMARY ........................................................................................................... 3
1. INTRODUCTION.................................................................................................................. 3
2. PAST STUDIES...................................................................................................................... 5
3. STUDY PROGRAMME ......................................................................................................... 5
   3.1. FIELD STUDY ............................................................................................................. 5
      3.1.1. Baal Bone Colliery .............................................................................................. 5
      3.1.2. Tahmoor Colliery ............................................................................................ 11
      3.1.3. Gujarat NRE No.1 Colliery .................................................................................. 15
   3.2. SUMMARY OF FIELD STUDY .................................................................................... 18
4. LABORATORY STUDIES ...................................................................................................... 20
   4.1. Push testing of the sectionalised fully-encapsulated threaded tubes ......................... 20
   4.2. Bolt pull testing in an overhead sandstone/concrete block ........................................ 25
   4.3. Resin Strength Properties .......................................................................................... 29
      4.3.1 Uni-axial Compressive Strength ......................................................................... 36
      4.3.2 Elastic Modulus of Elasticity ............................................................................. 37
      4.3.3 Punch shear test ................................................................................................. 37
      4.3.4 Rheological Properties (Creep) ......................................................................... 39
   Experimental Study ........................................................................................................... 39
      4.4.1. Sample Preparation ............................................................................................ 39
      4.4.2. Uni-axial Compression Strength and E-values test results .................................. 43
      4.4.3. Punch Shear Test Results: ............................................................................... Error! Bookmark not defined.
      4.4.4. Creep tests ......................................................................................................... Error! Bookmark not defined.
5. CONCLUSIONS AND RECOMMENDATIONS .................................................................... 67
ACKNOWLEDGEMENTS .......................................................................................................... 68
REFERENCES .......................................................................................................................... 68
APPENDICES ........................................................................................................................... 73
EXECUTIVE SUMMARY

In underground coal mining, the resin bond between the rock bolt and the strata is one of the critical elements of a roof bolting system, yet the Australian coal industry does not have an agreed standard for bolting system evaluation. A program of field and laboratory study was undertaken to examine various factors influencing the load transfer mechanism between the bolt, resin and rock. As per ACARP project requirement, the entire study used M24, 21.7 mm diameter X-grade Jennmar JBX bolts (APPENDIX B) and the standard Orica fast setting resin (APPENDIX Figure C). A series of Short Encapsulation Pull Tests (SEPTs) were carried out in three mines with different geological conditions. These mines were Baal Bone, Tahmoor and Gujarat NRE No.1. Additional studies included the evaluation of the anchorage performance along sections of bolts installed in steel tubes and variations in the strength properties of resin depending on sample dimensions. Furthermore, laboratory SEPTs were carried out on bolts installed in an overhead sandstone block mounted on a drill rig under environmentally controlled conditions. Factors of importance considered to affect bolt installation in strata include: borehole diameter, resin annulus thickness, installation time (including bolt spin to back and spin at back), the effect of gloving and its impact on installation quality and load transfer variation along the length of the installed bolt. 24 bolts were installed at each of Baal Bone and Tahmoor mines, and 16 bolts installed at Gujarat NRE No.1 mine. Installation of bolts in steel tubes was carried out at Springvale Colliery and subsequently tested in the Wollongong University Laboratory. The summary of the field studies found that:

- bolts installed in holes over-drilled by 50 mm resulted in relatively higher load transfer capacity for the given installation time,
- bolts installed in 27 mm diameter holes performed relatively better than those installed in 28 mm holes,
- in some cases over-spinning was detrimental to the load transfer capacity of the installed bolt,
- the influence of gloving was reduced with over-drilling,
- strength properties of resin tested at different length to diameter ratios did not vary considerably. In general, the length to diameter ratio of one was found to be a convenient dimension, and
- consistency of the strength values obtained from testing resin samples was dependent on the methodology of resin mixing and casting.

Various laboratory procedures for testing resins and grouts properties were evaluated as suggested by British and South African standards. Special emphasis was directed to the determination of the following resin /grout properties;

- Uniaxial Compressive Strength
- Young modules of elasticity
- Shear strength
- Creep tests.

The results from this evaluation revealed that some aspects of the British standards have shortcomings in sample preparation, testing and presentation of the results. Therefore, a new sampling and testing procedure have been developed as part of this study. Laboratory tests indicated that the proposed testing method is reliable, repeatable, easy to conduct and produces meaningful results when compared to underground tests. The new testing procedure is considered to be acceptable for testing resins used in Australia.

Because of the changes in emphasis on the project direction, this report is in two parts:
- Underground and the laboratory SEPT study findings, and
- Development of new testing procedures for the assessment of resin performance and a suggested method for SEPT.

1. INTRODUCTION

Over the past couple of decades, there has been significant interest in the performance of bolting system for strata stabilisation around openings in Australian underground coal mines. The resin bond between the rock bolt and the strata is one of the critical elements of a roof bolting system. The in situ installation effectiveness of roof bolting would be varied with
changing ground conditions, yet the Australian coal industry does not have an agreed standard for bolting system competency evaluation and continues to rely on other country’s’ standards, notably British, South African, and American to evaluate its bolting systems.

With increases in longwall geometry and need for continuity through difficult and challenging ground geology, ground support must withstand higher loads than ever before. Little work has been carried out on the assessment of the effectiveness of the encapsulation medium (resin) for bolt installation. The limited number of underground pull tests undertaken, which are available through various publications are insufficient and are hard to control and standardise. Therefore, the confidence of drawing definite conclusions about the performance of bolting system that may contribute to improved strata reinforcement is becoming hard to build up. A study focusing on providing a meaningful and consistent way of assessing resin/bolt interaction with high degree of confidence will offer significant benefits to both resin manufacturers and mine operators.

The initial objectives of the project were aimed at developing a standard test method for testing or assessing of different resins, based on: (a) the correlation of laboratory derived results with the actual performance of a roof bolt in the field (underground pull-out tests), and (b) development of a correlation index between the test results, which can be used by industry to select an appropriate resin for specific site conditions. Soon the project commenced, it was realised that the task of achieving the above objectives was enormous in the given timeframe. Also, there was a concern that a product to product comparative study may not be in the best interest of the resin manufacturers, which was not conducive to cooperative research in a healthy competitive marketing environment. Accordingly, new objectives were established during the first ACARP appointed monitors' meeting on February 15th 2012. These were:

1. Developing standard underground test procedures for SEPT for Australian standard roof bolts in 27-28 mm drill holes.
2. Determining the optimum drilling installation; a) drill rotation speed and b) thrust rates for standard Australian roof bolts in 27-28 mm drill holes.
3. Developing standard laboratory test procedures for determining resin mechanical properties from the contents of a finished goods capsule. The four important properties include:
   a) UCS,
   b) Modulus of Elasticity (E value).
   c) Shear Strength, and
   d) Creep.

The procedures or methods used should enable resin manufacturers to use them for routine Quality Control (QC) batch testing, and to allow mines to engage independent laboratories to verify results. On the basis of the above monitors’ directive, a programme of research study was decided to undertake:

a) SEPT conducted at three underground mines in different geological conditions. Selection of the mines were based on the availability of the appropriate test sites as well as positive management response,
b) Laboratory SEPT of bolts in an overhead sandstone block, paying particular attention to various parameters pertinent to bolt installation competency, such as drill motor rpm, drill thrust, over drill and bolt spin time.
c) Incremental evaluation of the load transfer capacity of the full length of encapsulated bolt by push testing of the equal length sections of the bolt,
d) Laboratory methods of testing resin properties from the contents of the finished goods (resin sausage) capsule, with the aim of defining clearly the changes in the mechanical properties of the resins, thus permitting the establishment of a standard method that can be used by industry for effective specification of resins, and
e) Preparation of procedures for SEPT and resin strength testing.

With Australian coal mines being fully dependent on the use of bolting technology for strata reinforcement in the vicinity of the mine workings and heading development, it is logical that mine operators and engineers become fully aware of the importance of the competency of the selected bolting system (i.e., bolt and resin) and not just rely on supplier’s directives and advice. The acquisition of such knowledge is relatively simple in comparison with other countries, notably USA, which
uses a variety of bolting systems (bolts and resins). The Australian usage of bolting systems is much more homogeneous with similar diameter bolts and with little diversity in the use of resin application until now. In light of the recent increases in various resin types application diversifications in Australian coal mines, there is a need for setting up a practical method of testing, by the end users of various resin properties with easily available testing facilities. Accordingly, this project is aimed to focus on finding easy ways for testing bolts both in the field and in the laboratory. These newly devised methods should provide operators an easy way to examine the quality of resins used in bolt installations in different ground formations and conditions.

2. PAST STUDIES

A number of papers pertinent to the aims and objectives of the project are worth reporting. Notable papers include; Altounyan et al., (2003) on developments in improving the standard of installation and bond strength of full column resin roof bolts; Wilkinson and Canbulat (2005) on the performance of bolt installations; Crompton and Oyler (2005) on investigation of fully grouted roof bolts installed under in situ conditions; Giraldo, et al., (2005) on improved pull out strength of fully grouted roof bolts through hole geometry modification; Campbell et al., (2004 and 2007) highlighting the importance of better understanding bolt installation methods and the build-up of the anchorage load along the installed bolt in a variety of ground conditions; Aziz , et al., (2013, 2006, 2008); Jalalifar and Aziz (2005) Jalalifar, Aziz and Hadi (2006) reported on the influence of bolt profile configuration on bolt load transfer capacity, under both push and pull testing; Zingano et al., (2008) on in situ tests and numerical simulation about the effect of annulus thickness on the resin mixture for fully grouted resin bolt; and most recently, Aziz, et al., (2013) reported on the bolt load transfer capability by push testing and on the simplified method of casting resin samples for strength property evaluation.

3. STUDY PROGRAMME

The revised project programme was aimed to maximise a possible outcome to the project’s aims and objectives, notwithstanding of the initial objective, consisting of;

- Field SEPT in underground coal mines,
- Load transfer capacity study of the bolt sections encapsulated in a steel tube,
- Laboratory SEPT in an overhead sandstone block,
- Study the strength properties of the resin used for bolt encapsulation,
- Deliverables which include ; (a) procedures for undertaking SEPT, both underground and in the laboratory, (b) suggested methods of determination of UCS, Young modulus, shear strength, and creep, and (c) methods of bolt installation for improved load bearing capacity.

4. FIELD STUDY

Three mines with different geological conditions were selected to examine the load transfer capacity of the bolt by short encapsulation tests. The selected mines were Baal Bone, Tahmoor and Gujarat NRE No1.

4.1. Baal Bone Colliery

4.1.1. Bolt installation and testing

The first SEPT field investigation was carried out at Baal Bone Mine. The mine is located in the Western coalfields of NSW, 32 km north of Lithgow and roughly 130 km from Sydney. The mine owned and operated by Glencore Pty Ltd, ceased production recently but has been kept open for care and maintenance and training purposes, therefore was readily available for the study. The mine has a competent roof, as demonstrated from the geological plan, shown in Figure 1. A total of 24 short encapsulation bolts were installed at Baal Bone. All bolts were installed in the Triassic mudstone/shale immediate formation above the Lithgow seam. All holes were drilled in a competent roof and the borescope survey showed no signs of fractures or discontinuities. Holes for bolt installation were drilled to a height of 1100 mm, which ensured that all holes stayed in the immediate mudstone formation below claystone bands. Drilling of holes and subsequent installation of bolts were carried out using a hand-held and compressed air-driven Alminco Gopher drill machine. The 23.7 mm (21.7 mm core)
Diameter X-grade bolts were used in the area as shown in Figure 2a. Figure 2b shows a typical pull testing setup. Each drilled hole was checked for diameter consistency within the top 300 mm of the hole using a three prong borehole calliper. The resin capsules of appropriate lengths were cut and resealed into smaller pieces to suit each installed bolt length. Figure 3 shows the schematic drawing of the encapsulated bolt and a photo of an in-line reamer.

The first 16 holes were reamed to a standard length of 900 mm of the 1100 long borehole length. Holes 17-20 were not reamed and holes 21-24 were reamed and 50 mm over-drilled above the bolt top end to allow for the possibility of forcing the shredded plastic film to accumulate along this length (Figure 3B). Generally, reaming was carried out using a 45 mm diameter inline reamer as shown in Figure 3C. The first four bolts were installed in 28 mm diameter holes, while the remaining 20 bolts were installed in 27 mm diameter holes. Orica / Minova RA33025F fast setting resin capsules were used to install bolts in drill holes. Bolts 17-20, with longer encapsulation length, were pull-tested after three hours of their installations and the rest of the bolts were pull-tested after one day of installation. It should be noted that the use of inline reamer is likely to interfere with drilling speed, and the rate of drilling of the main 27/28 mm drill head, once the 45 mm second drill head starts reaming of the hole. This obviously will alter the rifling profile pitch along the length of the encapsulated section of the drilled hole.

Figure 1-Geology of the Baal Bone immediate roof at heading test site
4.1.2. Results and analyses

Table 1 shows the summary of retrieved data of the bolt pull testing with subsequent analysis. The bond strength (kN/mm) was determined as the peak (maximum) pull load divided by the encapsulation length. The first eight bolts were installed in accordance with the standard installation time of ten seconds; however, there were some variations in time at the “spin to back” and “spin at back” as indicated in Table 1. Bolts 9-12 were installed in 5 s total time and bolts 13 to 16 took a much longer time period of installation, varying between 25 s to 42 s, particularly at the “spin at back” for “spin to stall” operation. Bolts 17 to 20, had encapsulation lengths greater than 300 mm, with hole diameter of 28 mm. Figure 4 shows the pull test load-displacement profiles of the first 16 bolts and Figure 5 shows load-displacement profiles of the remaining eight bolts. The average load-displacement values with respect to (a) installtion time and (b) reamed and un-reamed holes are shown in Figure 6.

Bolts 5, 6, 7 and 8 installed in smaller diameter holes of 27 mm achieved better load transfer capacity than bolts installed in 28 mm diameter boreholes (1, 2, 3 and 4). Contrary to findings by Wilkinson and Canbulat (2005), extra spin time did not produce good results. However, over-drilled holes performed better than the rest of the bolt installations. It is that the top 300 mm bond strength of most bolts, was significantly reduced, because of the accumulation of the capsule plastic film remnants in the over-drilled length. Thus the 50 mm over-drilled space allows shredded resin skin to accumulate in the over drill space above the bolt end and away from the encapsulated section of the bolt \ above the reamed section of the borehole. Consequently, the results showed a significant improvement. Thus, it is reasonable to conclude that the current short encapsulation pull test method used to study bond strength appears to demonstrate the effectiveness of over-drilling in...
Australian mines (Figure 5). Longer length encapsulation pull test results (bolts 17-20) were comparable to over-drilled bolt (21-24) installation as demonstrated in Table 1 and Figures 4 and 5. All spin times were kept constant at 10 seconds.

4.1.3. Summary

It can be inferred from the pull testing at Baal Bone that:

1. Bolt installation time of around 10 s constitutes an acceptable time for effective bolt installation as is normally recommended for use with Orica / Minova fast setting resin of 14 s,
2. The results of the over spinning at back was inconclusive, because of the limited bolt encapsulation length,
3. The use of 300 mm long encapsulation length may be the maximum acceptable length for pull testing, but this length depends on the type of the rock formation, which has some bearing on the load transfer capability of the installation. This finding is in agreement with the study carried out by Wilkinson and Canbulat (2005),
4. In-line reamer drill rod saved time for drilling reamed holes,
5. Hole over drilling contributed to increased load transfer capacity of the installed bolt, because the top space became the accumulation zone for the gloving material, thus reducing gloving concentration in the encapsulation length of the bolt, contributing better bonding of the bolt /resin and the host medium.

Table 1 - Analysed data from the short encapsulation pull tests-Baal Bone Mine

<table>
<thead>
<tr>
<th>Bolt No.</th>
<th>Peak Load (kN)</th>
<th>Bond Strength (kN/mm)</th>
<th>Displacement at Peak (mm)</th>
<th>Spin to Back (sec)</th>
<th>Spin at Back (sec)</th>
<th>Total Spin Time (sec)</th>
<th>Bond Length (mm)</th>
<th>Average Hole Dia. (mm)</th>
<th>Borehole Type</th>
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<td>4.7</td>
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<td>5</td>
<td>5</td>
<td>10</td>
<td>300</td>
<td>27</td>
<td>reamed + 50 mm OD</td>
</tr>
</tbody>
</table>

- **Bolt**: JBX, Core diameter: 21.7 mm, Length: 1200 mm, Installed horizon: 1100 mm; **Resin**: Orica, fast-setting, RA33025F.
- **Un-reamed holes encapsulation length** was achieved by wrapping tape around the end of the first 300 mm length of the bolt.
- Bond strength is defined as the maximum pull load/encapsulation length.
Figure 4: Variation in load transfer capacity at Baal Bone Mine with bolts pull tested with different hole diameters, hole configuration and bolt spin time.
Figure 5- Variation in bond load bearing capacity using different methods for rock bolt anchorage (various encapsulation lengths, reamed borehole and 50 mm over-drilling) - Baal Bone Mine

Test stopped as steel bolts yielded

Maximum applied load to the short encapsulated rock bolt system (kN)
5: 137.3  6: 176.2kN  7: 166.8  8: 147.2  [5+5]  Φ 27 mm
17-20: >200 bolts stretched due to excessive bond strength [5+5]  Φ 27 mm
4.2. Tahmoor Colliery

4.2.1 Bolt installation and pull testing

The next round of pull testing was carried out at Tahmoor Colliery in late November 2012. The mine is situated in the Southern Highlands region of NSW, approximately 75 km South West of Sydney and in the vicinity of the Tahmoor Township. The mine is owned and operated by Glencore Australia. Figure 7 shows the location of the test site at 5/1 intersection near the pit bottom.

Tahmoor mine produces coal from the Bulli Seam at a depth of 400-450 m. The coal seam roof is relatively stronger than the Lithgow measures of Baal Bone mine and comprises mudstone, shale and sandstone. Therefore, the mine roof at the test site can be described as moderately competent.

Similar to Baal Bone, a total of 24 bolts were installed in the intersection 5/1 near the pit bottom. The process of drilling and installation of 24 rock bolts as well as the equipment used was similar to the bolt installation operation at Baal Bone mine. Figures 8A and 8B show typical SEPT installation and measuring equipment used in the mine.

During the drilling operation, holes 1-4, 9-12 and 17-20 were reamed as standard holes. Holes 5-8, 13-16 and 21-24 were not reamed but were over-drilled up to 50 mm. Drilling and reaming was carried out using a combined 27 mm drill bit with an inline reamer of 45 mm diameter as shown in Figure 3C. As in previous practice at Baal Bone, resin capsules (type: RA33025F) were used for bolt installation. The bolts used at Tahmoor Mine were the same type as that used at Baal Bone Mine. The interval between bolt encapsulation and pull test times was around two hours.

Two encapsulation lengths of 200 mm and 300 mm lengths were trialled at Tahmoor, with and without the additional 50 mm of over drilling. The installation time of the bolts was mostly in accordance with the normal standard time of 10 s; however, there were some variations, mostly at lower installation times as shown in Table 2.
4.2.2. Results and analysis

Table 2 highlights the summary of test results and analysis. The 200 mm long short encapsulation pull tests for the first eight bolts (1-8) showed a variation in bond strength between the standard hole length and the 50 mm over-drilled holes. The over-drilled holes pull test values were, in most cases, higher than the standard installations. The influence of over-drilling is also evident with bolts installed at short installation time in bolts 22 and 24. Similar to the Baal Bone Mine study, the over-drilled holes generally showed a significant improvement in the load bearing capacity of bolt installations. Within over-drilled bolts with 200 encapsulation length, bolt 5 had the highest bond strength at around 167 kN, with mixing time of 5 s “spin to back” plus 5 s “spin at back” (Figure 9). All holes were 27 mm in diameter. As expected, pull test results for 300 mm long encapsulation length yielded stronger bond strength, which, at times, exceeded the yield strength of the bolt as shown in Appendix B.

It is not possible to draw a realistic and comparative conclusion between the standard 300 mm long encapsulation with and without over-drilling (bolts 9 to 16) as pull test loads were close to bolt yield strength. However, the narrow and higher margins in pull loads were evident in over-drilled hole bolt installations, hence it is reasonable to assume that the over-drill installation pull load values were better than the standard bolt installations. The profiles of the load-displacement graphs are shown in Figures 10 to 12. Figure 13 shows the plotted average values
Table 2 - Processed data from short encapsulation pull tests - Tahmoor Mine

<table>
<thead>
<tr>
<th>Bolt No.</th>
<th>Peak Load (kN)</th>
<th>Bond Strength (kN/mm)</th>
<th>Displacement at Peak (mm)</th>
<th>Spin to Back (sec)</th>
<th>Spin at Back (sec)</th>
<th>Total Spin Time (sec)</th>
<th>Bond Length (mm)</th>
<th>Borehole Type</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>98.1</td>
<td>0.49</td>
<td>2.6</td>
<td>5</td>
<td>5</td>
<td>10</td>
<td>200</td>
<td>reamed</td>
</tr>
<tr>
<td>2</td>
<td>127.5</td>
<td>0.64</td>
<td>4.3</td>
<td>5</td>
<td>5</td>
<td>10</td>
<td>200</td>
<td>reamed</td>
</tr>
<tr>
<td>3</td>
<td>127.5</td>
<td>0.64</td>
<td>2.3</td>
<td>5</td>
<td>5</td>
<td>10</td>
<td>200</td>
<td>reamed</td>
</tr>
<tr>
<td>4</td>
<td>127.5</td>
<td>0.64</td>
<td>3.9</td>
<td>5</td>
<td>5</td>
<td>10</td>
<td>200</td>
<td>reamed</td>
</tr>
<tr>
<td>5</td>
<td>166.8</td>
<td>0.83</td>
<td>2.6</td>
<td>5</td>
<td>5</td>
<td>10</td>
<td>200</td>
<td>reamed + 50 mm OD</td>
</tr>
<tr>
<td>6</td>
<td>137.3</td>
<td>0.69</td>
<td>2.4</td>
<td>5</td>
<td>5</td>
<td>10</td>
<td>200</td>
<td>reamed + 50 mm OD</td>
</tr>
<tr>
<td>7</td>
<td>147.2</td>
<td>0.74</td>
<td>3.4</td>
<td>5</td>
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<td>10</td>
<td>200</td>
<td>reamed + 50 mm OD</td>
</tr>
<tr>
<td>8</td>
<td>107.9</td>
<td>0.54</td>
<td>1.8</td>
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<td>5</td>
<td>10</td>
<td>200</td>
<td>reamed + 50 mm OD</td>
</tr>
<tr>
<td>9</td>
<td>235.4</td>
<td>Long encapsulation</td>
<td>4.6</td>
<td>5</td>
<td>5</td>
<td>10</td>
<td>300</td>
<td>reamed</td>
</tr>
<tr>
<td>10</td>
<td>201.1</td>
<td>0.67</td>
<td>6.3</td>
<td>5</td>
<td>5</td>
<td>10</td>
<td>300</td>
<td>reamed</td>
</tr>
<tr>
<td>11</td>
<td>235.4</td>
<td>Long encapsulation</td>
<td>3.2</td>
<td>5</td>
<td>5</td>
<td>10</td>
<td>300</td>
<td>reamed</td>
</tr>
<tr>
<td>12</td>
<td>235.4</td>
<td>Long encapsulation</td>
<td>4.4</td>
<td>5</td>
<td>5</td>
<td>10</td>
<td>300</td>
<td>reamed</td>
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<tr>
<td>13</td>
<td>186.4</td>
<td>0.62</td>
<td>3.2</td>
<td>5</td>
<td>5</td>
<td>10</td>
<td>300</td>
<td>reamed + 50 mm OD</td>
</tr>
<tr>
<td>14</td>
<td>225.6</td>
<td>Long encapsulation</td>
<td>4.0</td>
<td>5</td>
<td>5</td>
<td>10</td>
<td>300</td>
<td>reamed + 50 mm OD</td>
</tr>
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<td>300</td>
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<td>16</td>
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<td>300</td>
<td>reamed + 50 mm OD</td>
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<td>5</td>
<td>200</td>
<td>reamed</td>
</tr>
<tr>
<td>18</td>
<td>63.8</td>
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<tr>
<td>19</td>
<td>98.1</td>
<td>0.49</td>
<td>2.0</td>
<td>3</td>
<td>2</td>
<td>5</td>
<td>200</td>
<td>reamed</td>
</tr>
<tr>
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<td>0.17</td>
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<td>3</td>
<td>2</td>
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<td>200</td>
<td>reamed</td>
</tr>
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<td>21</td>
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<td>0.54</td>
<td>11.7</td>
<td>3</td>
<td>2</td>
<td>5</td>
<td>200</td>
<td>reamed + 50 mm OD</td>
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<td>0.69</td>
<td>2.4</td>
<td>3</td>
<td>2</td>
<td>5</td>
<td>200</td>
<td>reamed + 50 mm OD</td>
</tr>
<tr>
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<td>98.1</td>
<td>0.49</td>
<td>1.5</td>
<td>3</td>
<td>2</td>
<td>5</td>
<td>200</td>
<td>reamed + 50 mm OD</td>
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<tr>
<td>24</td>
<td>147.2</td>
<td>0.74</td>
<td>1.9</td>
<td>3</td>
<td>2</td>
<td>5</td>
<td>200</td>
<td>reamed + 50 mm OD</td>
</tr>
</tbody>
</table>

NB: OD – over drill. All encapsulated holes diameter: 27mm. All holes reamed. Bond strength (kN/mm) is the peak (maximum) pull load divided by the encapsulation length.

Figure 9- Variation in load bearing capacity of the first eight bolts (1-8) using different installation methods for rock bolt anchorage at Tahmoor Mine (reamed hole and 50 mm over drill)
Figure 10- Variation in load bearing capacity of the bolts 9-16 using different methods for roof bolt anchorage at Tahmoor Mine (reamed hole and 50 mm over drill)

Figure 11- Variation in load bearing capacity of rock bolts 17-24 using different installation methods (reamed borehole and 50 mm over drill)-Tahmoor Mine
Figure 12 - Tahmoor (a) 200 mm V 300 mm Bond Length, (b) Reamed V Reamed Over drill. Average values

With regard to short installation times, it is clear that shorter installation spin times less than ten seconds were inadequate for proper resin mixing to allow effective anchorage and hence a relatively lower peak pull load strength. Again over drilling appears to yield relatively superior bond strength.

4.2.3. Summary

Thus, it can be inferred from the tests carried out at Tahmoor Colliery that:

- bolts installed in over-drilled holes had superior load transfer capacity, irrespective of the anchorage length of either 200 or 250 mm,
- as expected, the 300 mm encapsulation length yielded greater load transfer capacity (higher pull force values) leading to yield strength, and
- shorter installation time of less than the standard 10 sec was counter-productive for effective load transfer mechanism. Prolonged “spin time at back” and shorter “spin time to back” is also counter-productive.

4.3 Gujarat NRE No.1 Colliery

4.3.1 Bolt installation and pull testing

The third and final round of field tests was carried out in mid-December, 2012 at NRE No.1 Colliery situated in the Southern Coalfields of NSW, approximately 60 km South of Sydney, 10 km north of Wollongong and in the vicinity of Russell Vale Township.

Gujarat NRE No.1 Colliery currently mines both the Bulli Seam and the Wongawilli Seam. The test site was located in C heading, between CT20 and CT21 of the Wongawilli Seam East main headings as shown in the mine plan (Figure 13). The
selected stratification above the working headings is as shown in the mine plan. The selected stratification above the working part of the Wongawilli Seam was a soft formation of mainly coal layers and clay bands as shown in Appendix A 2-4.

![Figure 13- Gujarat NRE No.1 mine plan showing the study area in the vicinity of the mine pit bottom](image)

**Installation and pull testing**

Similar to previous field studies, an even and flat roof area was selected at the CT20 intersection for bolt installation as shown in Figure 13. A total of 16 bolts, 1200 mm long, were installed in 1100 mm long holes using a handheld and compressed air operated Alminco Gopher drill. All bolts were installed using Orica / Minova fast setting resin type RA33025F. Typical installation of rock bolts and measuring equipment used are shown below (Figures 14A and 14B).

Table 3 shows details of pull testing results. Drilling and reaming of holes were accomplished using an in-line reamer.

- All holes were drilled using 27 mm wing bits. Reamed sections were 45 mm in diameter.
- Encapsulation length of the first 12 holes was constant at 300 mm and encapsulation lengths of holes 13 to 16 holes were variable as indicated in Table 3.
- Bolts 1 to 4 were installed in 50 mm long over-drilled holes with a reamed 200 mm top section. The installation time was consistent at standard time of ten seconds (5 s “spin to back” and 5 s “spin at back”).
- Bolts in holes 9 to 12 were installed at the total spin time of five seconds (2 s “spin to back and 3 s “spin at back”).
- In unreamed holes13-16, the desired anchorage length of holes 13 to 16 were accomplished by wrapping an insulation tape of sufficient thickness around the bolt to the determined length, thus preventing the resin from spreading down the length of the bolt.

The time between bolt installation and pull test was nearly three hours for all bolts. The length of resin capsule for each hole was calculated and the correct length was cut from the longer resin capsule and re-sealed accordingly. The length of each resin capsule used in 300 mm encapsulation for effective anchorage was 250 mm.

Table 3 shows the current 300 mm short encapsulation pull test for the first 12 rock bolts. As can be seen from Figure 15, un-reamed holes with variable encapsulation length have better load bearing capacity, up to 196 kN, in comparison with performance of reamed holes with 300 mm encapsulation length. Figure 16 shows the load-displacement graphs of
NB: BH encapsulated length diameter 27 mm, using twin-wing bit
Holes 1-12 were reamed using a 45 mm diameter in-line reamer

1-8 bolts. It is clear that the performance of the first four bolts (bolts 1-4) installed in over-drilled holes was better than the bolts installed with the standard methods and without over-drilling (bolts 5-8). As can be seen from Figure 17, the drilling method used in reamed holes, as the standard practice, had various spin times resulting in different load bearing capacity of bonded bolts of up to around 160 kN. Generally bolts with the total spin time composition of 2+3 s performed better than those with 10 s spin time (5+5 s), and that over-drilling improves the performance of encapsulation load bearing capacity of a bolt in comparison with the standard reamed boreholes. In addition, over mixing at back resulted in higher bond strength (Figure 17).

4.3.2. Summary

The following were inferred from pull tests at Gujarat NRE No.1 Mine installations in the Wongawilli formation:

1. Bolts installed in over-drilled holes (bolts 1-4) had relatively higher pull loads than standard holes 5 and 8 and without over-drilling.
2. The pull load of bolts installed at shorter installation spin time was, in general greater than the standard 10 s time.
3. As expected, the bolt installed with anchorage length of 320 mm in length was greater than the 300 mm encapsulation length. This additional length of 20 mm encapsulation length appears to give readings near the value of the bolts installed in 50 mm over-drilled holes, in other words the load generated was near the bolt's yield point.

4.4. SUMMARY OF FIELD STUDY

Given the limited number of bolts installed at three sites of varying geological formations, it is clear that over-drilling of bolts by 50 mm has resulted into load transfer capacity improvement. This increase in bolt resin rock bonding can be attributed to the resin sausage skin being pushed upwards and accumulating in the over drill space above the bolt end. The removal of the shredded skin from the main body of the resin mixture may have permitted an improvement in bonding strength between the bolt, resin and rock. This finding is further discussed in the analysis of the sectionalised bolts in tube encapsulated installation analysis, as well as in pull testing of installed bolts in an overhead sandstone/concrete block in the laboratory as discussed in section (CCC).

![Figure 15- Bolt installation times in 27 and 28 mm holes. Holes 5-8 were reamed and holes 13-16 un-reamed, Gujarat NRE No.1 Mine](image)
Figure 16- Variation in load bearing capacity for different installations lengths (borehole 50 mm over drilling)-NRE No.1 Mine

Figure 17- Variation in load bearing capacity applying different methods to bolt anchorage (various “spin to back” and at back timings)-NRE No.1
5. LABORATORY STUDIES

As a part of the ACARP project, a series of laboratory pull tests were carried out in a favourable and convenient environment to supplement the findings from the field studies. The laboratory study was a three pronged experimental work consisting of:

a) Push testing of the sectionalised 100 mm fully-encapsulated bolts in steel tubes brought back from Springvale Colliery,
b) Pull testing of installed bolts in an overhead sandstone/concrete block, and
c) Strength properties of resin used for bolt installation.

5.1. Push Testing of Sectionalised Fully-encapsulated Bolts Installed in Threaded Tubes

5.1.1 First batch

In this test four bolts were installed and encapsulated in steel pipes at Springvale Colliery. A hydraulic drill with 400-500 rpm motor spin was used to install the bolts in the hollow tubes, inserted in holes drilled into the heading roof. The 1.7 m long threaded tubes of 28.5 mm internal diameter, and sealed at the top end, were then retrieved from the mine and brought back to the University of Wollongong Rock Mechanics Laboratory for load transfer capacity push testing. Bolt encapsulation times (“spin to back” and “spin at back”) were varied as per the requirements for testing in different conditions. The bolt (X-grade JBX bolts) and Minova/Orica fast-setting resin type RA33025F, used in the previously test sites, were also used in this study. During the installation process the resin reached the collar of the tubes on every installation. The breakdown of mixing time was set as follows:

- Bolt 1: “spin to back”= 10 s, “spin at back”= 4 s, total= 14 s
- Bolt 2: “spin to back”= 10 s, “spin at back”= 4 s, total= 14 s
- Bolt 3: “spin to back”= 6 s, “spin at back”= 2 s, total= 8 s
- Bolt 4: “spin to back”= 12 s, “spin at back”= 18 s, total= 30 s

After retrieving tubes from the mine, the samples were cut into 100 mm sections and push tested using a 50 tonnes capacity Instron Universal Testing Tachine. Figure18 shows a typical sectionalised encapsulated bolt used in the study.

The methodology of push testing of the bolt from the steel tube was similar to the test procedure reported by Hillyer, et al., (2013). Using a hollow steel tube of a suitable diameter, the tube was machined at one end to produce a seat so that the encapsulated section of the tube can sit on the tube rim thus enabling the bolt section to be pushed out as shown in. A 200 mm hardened steel rod was clamped to the upper jaws of the Instron testing machine was used to push out the bolt as shown as shown in Figure 19. The rate of pushing the bolt out of the steel was in the order of 1 mm /min.

![Figure 19- Sectionalised 100 mm encapsulated bolt tubes](image-url)
The summary of all push test results is shown Figure 20 A-D). There were few sections along bolts 1, 2, and 3 in which the resin was not mixed properly and accordingly no bonding was generated. Figure 21 shows typical load-displacement profiles of sectionalised bolts and post push encapsulation annulus view. Closer observation of push testing results of the various 100 mm long sections of the sectionalised pieces revealed that:

- Poor mixing of the resin resulted in complete loss of resin bonding in the vicinity of the collar and up to a third of the way up in the tubes. This loss of bonding was clearly evident in a number of the sectionalised bolted tube sections is shown in Figures 20, A, B and C.
- The bonding strength reduced to almost zero, which at times had the encapsulated bolt sections with unmixed resin falling freely out of the outer tube. Only bolts installed in tube D had relatively good encapsulation.
- Higher bonding was achieved in various bolt sections at around mid-length of the bolt. A possible reason for failure in effective encapsulation along the bolt in tube was unclear as the procedure used for installing the bolts in the tubes was similar to past practices.
- The team installing these bolts was the same team that installed previous similar studies as reported by Hillyer, et al., (2013). One possible explanation given may be due to slow drill motor spin at < 400 rpm and the relatively larger size of the tube hole internal diameter of 28 mm. Clearly, this study required further trials.
Figure 20 - Analysis of sectionalised fully-encapsulated bolts

Figure 21 - Typical Load-Displacement profiles of the 100 mm long encapsulated bolt sections, and general view of the sections surface
5.1.2 Second Batch

A second batch of four new bolts was installed in steel tubes in an underground roadway at Spring Vale Colliery in Lithgow, NSW. These encapsulated bolts in steel tubes were retrieved from the mine and brought back to the UOW laboratory for sectionalisation and push testing. Figure 22 shows the retrieved four encapsulated bolts. Each encapsulated tube in the batch were clearly numbered and painted for identification. Bolt installation time in each tube was as follows:

- Bolt 1: “spin to back” = 7 s, “spin at back” = 7 s, total = 14 s
- Bolt 2: “spin to back” = 10 s, “spin at back” = 4 s, total = 14 s
- Bolt 3: “spin to back” = 7 s, “spin at back” = 7 s, total = 14s [encapsulated tube 50 mm longer than the bolt, to simulate over drill.]
- Bolt 4: “pin to back” = 7 s, “spin at back” = 38 s (until pin break).

All four 2.1 m long bolts were encapsulated in 1.8 m long steel tubes using Orica/Minova standard resin capsules. Each steel tube had an outer diameter of 48 mm and an inner diameter of 30 mm with an internal threading of 2 mm. All bolts were installed using a constant drill rotational speed of 450 rpm.

Figure 23 shows peak load profiles of the various sections, together with their respective trend lines. The graph colours depict the peak loads and trend lines of a particular encapsulated tube as identified by similar colours.

Figure 24a shows the 100 mm long sections of bolt 3. This bolt had a top cap of 50 mm as over drill. A length of approximately 50 mm of resin skin was pulled out of the over drill section as shown in Figure 24b. It is noticeable that, due to the over drill, the top part of the resin cartridge was not thoroughly mixed, causing weaker encapsulation, leading to much, nevertheless higher bonding strength in comparison with other three encapsulated bolt ends when tested. This suggests that the gloving has migrated to the top end cumulating in the top 50 mm of the un-encapsulated and otherwise empty end of the steel tube, leaving the rest of the lower sections of the bolt with relatively strong bonding strengths as it is evident from the sectionalised N to S encapsulated sections shown in Figure 22. Figure 24 shows the level of gloving accumulations at the top end of other bolts (bolts 2, 3 and4). A comparison analysis of the top 700 mm section of the bolt in section O to S, shows that Bolt No 3 has out-performed the other no over-drilled bolts. The next best performing bolt was Bolt No 2, and
least was No 4. Excessive over spinning of the bolt has clearly over weakened and succeeded the strength properties of the encapsulation resin. Another point of significance is that compliance to the resin manufacturer’s installation time is desirable as the recommended installation of the resin was 14 s. Thus, it is suffice to suggest at this stage and with limited test undertaken that over-drilling of holes appears to contribute an improvement in the load transfer capacity characteristics of the installed bolt. This aspect of the study is the subject of further study undertaken in the laboratory experiments discussed in the following section (section 4.2).

![Figure 23](image)

**Figure 23**: Analysis of the second batch of sectionalised fully-encapsulated bolts

<table>
<thead>
<tr>
<th>SECTIONS</th>
<th>Load values of regressive trendlines (kN)</th>
<th>Bond strength improvement due to over-drilling (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>O</td>
<td>P</td>
</tr>
<tr>
<td>Bolt 1 - [7+7 s]</td>
<td>135</td>
<td>116</td>
</tr>
<tr>
<td>Bolt 2 - [10+4 s]</td>
<td>151</td>
<td>132</td>
</tr>
<tr>
<td>Bolt 3 - [7+7 s] + over-drill</td>
<td>159</td>
<td>147</td>
</tr>
<tr>
<td>Bolt 4 - [7+38 s] until pin breaks</td>
<td>117</td>
<td>107</td>
</tr>
</tbody>
</table>

**Figure 24**: (a) Sectionalised over-drilled encapsulated bolt in a steel tube No 3 and (b) the 50 mm end over-drilled section with unmixed resin capsule end excessive shredded gloving
The main aim of this study was to test bolting system installed in an overhead sandstone block cast in concrete to verify testing studies conducted underground. The 0.7 m³ sandstone block was cast in 40 MPa sand/mortar that was allowed to cure for approximately two months. A total of 36 bolts were pull tested to verify the results of the field studies carried out in three different mines as well as the bolts installed in steel pipes. Holes in the overhead block were drilled in the lower half of the sandstone blocks (Figure 25). Holes were drilled using a hydraulic drill rig and a 27 mm diameter drill bit with 45 mm inline reamer (Figure 3C). Figure 26 shows the schematic drawing of boreholes location arrangement in the lower half in the overhead sandstone/concrete block.

Holes were drilled 400 and 450 mm in length with some an additional 50 mm over-drill. Minova/Orica Lokset fast-set resin capsules were used to encapsulate bolts in 200/250 mm length of holes. The resin capsules were cut into 200 mm long pieces and re-sealed. The 50 mm over drilling was used to evaluate the influence over drilling on bolt anchorage performance and to confirm the results of over drilling from field studies.

A correct bolt encapsulation length was necessary, as each extra centimetre of the encapsulation length was found to increase the bond force of the installed bolt by up to 10 kN (1 t). Accordingly, the drill steel rod was marked at the appropriate length to ensure a correct depth being drilled. The 1200 mm long as supplied JBX bolts were cut to a length of 900 mm to accommodate both the bolting length in the sandstone block and allow mounting of the testing equipment to the protruding length of the tested bolt for monitoring as shown in Figure 25. The holes were appropriately designated for specific purpose of pull testing with different bolt installation times to mimic tests in underground, including 50 mm over drill.
Figure 27- Drilling holes in an overhead sandstone/concrete block and pull test assembly

Figure 28- Schematic drawings of boreholes arrangement
(A): bottom plan view, (B): side view

5.2.1 Batch 1: installation and pull testing

Table 4 shows the details of the first 14 bolts installed and pull tested in sandstone block. It was not possible to install a bolt in Hole E3, as the process of installing the bolt with spin to stall was impossible to achieve with short encapsulation length of 200 mm. This is because the resin was overspinnd and lost strength due to the high drill speed of 600 rpm that was used in this particular installation. Subsequently, the drill speed was adjusted to 500 rpm for the remainder of bolt installtions. Figure 29 shows the load displacement of 12 bolts out of 14 bolts listed in Table 4. The peak loads are varied because of varying bolt installation conditions. Figure 30 shows bar charts of the peak pull loads.
Figure 31 shows the load displacement of the first batch of four bolts, which were over drilled by 50 mm leaving a length of 250 mm of bolt installation encapsulation. The install time was maintained at 10 sec (5 sec spin to back and 5 sec at back). The pull force of the four bolts varied between 84 and 100 kN, with an average pull force values (bond strength) of 92.75 kN (0.46 kN/mm). The second batch of five bolts (C2, C3, C4, D6) were installed with encapsulation length of 250 mm and no over drill. The installation time was maintained at 10 s, the pull out force was varied between 180 and 203 kN with an average pull load of 218.5 kN as shown in Figure 32. This being equal to average bond strength of 1.14 kN/mm. Only three bolts were successfully pull tested from batch three of five bolts (A3, A4, A5, B3 and B5) with 250 mm encapsulation at 3/7 sec installation time. The average pull load of only three bolts, discarding bolts B3 and A4, was 174 kN (0.696 kN/mm) as shown in Figure 33. If one include all five bolts in the batch, then the average pull load will be in the order of 0.57 mm/sec. All holes were reamed for the first 200 mm lower length section.

Closer examination of the test results in Table 4 indicated that;

1) The first batch of the over drilled yielded poor results because of the significant resin quantity was accumulated in the over drill space and the remaining resin was insufficient to encapsulate fully the 200 mm length of the designated bolt length, hence poor anchorage performance. In another way the sausage length of 200 mm was not sufficient to effectively encapsulate the bolt in the hole.
2) 3/7 s installation time combination appears to be inferior to 5/5 sec. This is in agreement with that achieved form the field study.

Figure 34 shows the accumulation of the encapsulation shredding in the over drilled 50 mm length of a hole, photographed by a bore hole camera in the laboratory overhead sandstone block.

---

Figure 29- Variation in load bearing capacity of bolts using the same spin time during installation in the overhead block (3 s “to back”+7 s “at back”)
<table>
<thead>
<tr>
<th>Test</th>
<th>Bolt</th>
<th>Encapsulation length and time</th>
<th>Installation status</th>
<th>Pull load (KN)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>E3</td>
<td>Spin/stall</td>
<td>Unsuccessful</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>D4</td>
<td>over-drilled 50 mm, encapsulation 250 mm.</td>
<td>Good installation Reamed lower 200 mm section</td>
<td>89</td>
</tr>
<tr>
<td>3</td>
<td>C6</td>
<td>over-drilled by 50 mm, 10 s spin time</td>
<td>Bolt outer section slightly bent due to being pushed aside by the drill rig. Reamed</td>
<td>98</td>
</tr>
<tr>
<td>4</td>
<td>D2</td>
<td>over-drilled 50 mm (250 mm encapsulation)</td>
<td>Good installation Reamed</td>
<td>100</td>
</tr>
<tr>
<td>5</td>
<td>D3</td>
<td>over-drilled 50 mm (250 mm encapsulation)</td>
<td>Good Installation. Reamed</td>
<td>84</td>
</tr>
<tr>
<td>6</td>
<td>D6</td>
<td>250 mm encapsulation and no over drill, 10 s spin</td>
<td>Reamed</td>
<td>231</td>
</tr>
<tr>
<td>7</td>
<td>C2</td>
<td>250 mm encapsulation and no over drill, 10 s spin</td>
<td>Reamed</td>
<td>180</td>
</tr>
<tr>
<td>8</td>
<td>C3</td>
<td>250 mm encapsulation and no over drill, 10 s spin</td>
<td>Reamed</td>
<td>260</td>
</tr>
<tr>
<td>9</td>
<td>C4</td>
<td>250 mm encapsulation and no drill, 10 s spin</td>
<td>Reamed</td>
<td>203</td>
</tr>
<tr>
<td>10</td>
<td>B3</td>
<td>3 s to back, 7 s at back</td>
<td>Problems with installation, Reamed</td>
<td>120</td>
</tr>
<tr>
<td>11</td>
<td>B5</td>
<td>3 s to back, 7 s at back</td>
<td>Good installation, reamed</td>
<td>153</td>
</tr>
<tr>
<td>12</td>
<td>A5</td>
<td>3 s to back, 7 s at back</td>
<td>Good installation, reamed</td>
<td>197</td>
</tr>
<tr>
<td>13</td>
<td>A4</td>
<td>3 s to back, 7 s at back</td>
<td>Bent protruding bolt end, reamed</td>
<td>73</td>
</tr>
<tr>
<td>14</td>
<td>A3</td>
<td>3 s to back, 7 s at back</td>
<td>Good installation, reamed</td>
<td>173</td>
</tr>
</tbody>
</table>

![Graph showing load (KN) against bolts D2 to B5]
Figure 30 - Bar chart peak pull load of various bolts from Table 4

Figure 31 - (a) Load-displacement profiles of the bolts installed with 10 s (3/7s) and (b) post pull out bolts showing the level of encapsulation along different bolts. No over drill and encapsulation length 250 mm

Figure 32 - (a) Load-displacement profiles of the bolts installed with 10 s (5/5s) and (b) post pull out bolts showing the level of encapsulation along different bolts. 250 mm encapsulation and no over drill
5.2.2. Batch 2: installation and pull testing

Table 5, shows details of the second batch of nine bolts installed with 250 mm long Orica resin cartridges. All bolts had encapsulation length of 250 mm. One bolt installation “A3” was over encapsulated with 300 mm cartridge, thus yielding higher pull load. The remainder eight bolts were installed with four being over drilled by 50 mm. As can be seen from graphs in Figure 32a and bar chart in Figure 32 b, the performance of the over drilled bolts were marginally better than no over-drill bolts. Figure 33 shows the photos of the bolts with varying encapsulation lengths. No comparison could be made about the installation timing because of the limited number of tests and other variables such as over drill.

Table 5- Batch 2 bolts installation and pull out peak loads

<table>
<thead>
<tr>
<th>No</th>
<th>Bolt/Hole</th>
<th>Encapsulation length and over drill</th>
<th>Installation time</th>
<th>Failure load (kN)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>A1</td>
<td>200 mm, 50 mm over drill</td>
<td>10 s (5/5)</td>
<td>159.16</td>
</tr>
<tr>
<td>2</td>
<td>A2</td>
<td>200 mm, 50 mm over drill</td>
<td>10 s (5/5)</td>
<td>191.04</td>
</tr>
<tr>
<td>3</td>
<td>A3</td>
<td>300, no over drill</td>
<td>10 s (5/5)</td>
<td>205.46</td>
</tr>
<tr>
<td>4</td>
<td>B1</td>
<td>200 mm, 50 mm over drill</td>
<td>10 s (5/5)</td>
<td>145.75</td>
</tr>
<tr>
<td>5</td>
<td>B2</td>
<td>300, no over drill</td>
<td>10 s (5/5)</td>
<td>28.25</td>
</tr>
<tr>
<td>6</td>
<td>B3</td>
<td>200, no over drill</td>
<td>3s /10 s stall</td>
<td>105.79</td>
</tr>
<tr>
<td>7</td>
<td>C1</td>
<td>200 mm, 50 mm over drill</td>
<td>10 s (5/5)</td>
<td>146.12</td>
</tr>
<tr>
<td>8</td>
<td>C2</td>
<td>200, no over drill</td>
<td>5 s to back, 13s to stall</td>
<td>Unsuccessful</td>
</tr>
<tr>
<td>9</td>
<td>C3</td>
<td>Encapsulation 200, no over drill</td>
<td>5s /13 s pin break</td>
<td>128.48</td>
</tr>
</tbody>
</table>
Figure 32- (a) load displacement profiles of bolts tested in batch 2 and (b) bar chart of bolts peak pull load. Bolt 3 was over encapsulated by an additional 100 mm resin capsule
Figure 33 – pulled out bolts of batch 2 test.

5.2.3. Batch 3: installation and pull testing

Table 6 shows performance of nine bolts installed with 250 mm long resin capsuled with five bolts being 50 mm over drill and the other four with no over drill. All the bolts were installed with 5/5 sec installation time. It is clear from Figure 34 that the quantity of resin was sufficient to allow the bolts to be installed effectively in both installed types (over drill and no over drill holes). Upon inspection of the installed bolts in the holes, it was clear that there was a significant over spill resin in the reamed section of the holes, which might contributed to additional length of bonding between the bolt and the rock/concrete hole wall; however, the length of reamed section encapsulation was less in over drilled holes in comparison with no over drill holes. This level of over spill is also clear in post pulled out bolts as shown in Figure 35.

Table 6- Batch 3 installations details

<table>
<thead>
<tr>
<th>No.</th>
<th>Code</th>
<th>Over drill</th>
<th>Encapsulation length</th>
<th>Ream length</th>
<th>Resin encapsulation length</th>
<th>Peak load</th>
<th>Drill dia.</th>
<th>Ream dia.</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>C4</td>
<td>no</td>
<td>230</td>
<td>200</td>
<td>230</td>
<td>109</td>
<td>28</td>
<td>45</td>
</tr>
<tr>
<td>2</td>
<td>B4</td>
<td>no</td>
<td>230</td>
<td>200</td>
<td>230</td>
<td>206</td>
<td>28</td>
<td>45</td>
</tr>
<tr>
<td>3</td>
<td>A4</td>
<td>no</td>
<td>230</td>
<td>200</td>
<td>230</td>
<td>208</td>
<td>28</td>
<td>45</td>
</tr>
<tr>
<td>4</td>
<td>D4</td>
<td>no</td>
<td>230</td>
<td>200</td>
<td>230</td>
<td>132</td>
<td>28</td>
<td>45</td>
</tr>
<tr>
<td>5</td>
<td>D3</td>
<td>no</td>
<td>230</td>
<td>200</td>
<td>230</td>
<td>116</td>
<td>28</td>
<td>45</td>
</tr>
<tr>
<td>6</td>
<td>C3</td>
<td>yes</td>
<td>230</td>
<td>200</td>
<td>300</td>
<td>149</td>
<td>28</td>
<td>45</td>
</tr>
<tr>
<td>7</td>
<td>B3</td>
<td>yes</td>
<td>230</td>
<td>200</td>
<td>300</td>
<td>63</td>
<td>28</td>
<td>45</td>
</tr>
<tr>
<td>8</td>
<td>A3</td>
<td>yes</td>
<td>230</td>
<td>200</td>
<td>300</td>
<td>181</td>
<td>28</td>
<td>45</td>
</tr>
<tr>
<td>9</td>
<td>C2</td>
<td>yes</td>
<td>230</td>
<td>200</td>
<td>300</td>
<td>115</td>
<td>28</td>
<td>45</td>
</tr>
<tr>
<td>10</td>
<td>between B&amp;C, 2&amp;3</td>
<td>yes</td>
<td>230</td>
<td>200</td>
<td>300</td>
<td>86</td>
<td>28</td>
<td>45</td>
</tr>
</tbody>
</table>
Figure 34a – Load displacement of bolts from Batch three bolts

Figure 34b – Bar chart of peak pull loads of batch three bolts

Figure 35 – Post pull test batch three bolts. Yellow arrow indicate over drilled bolts
5.2.4. Batch 4: Installation and pull testing

Figure 36 shows the results of the fourth installation of five bolts with four 250 mm long resin capsules and one 230 mm. Three holes were over drilled by 50 mm and the other two holes were not over drilled. The encapsulated length of the bolt in no over drilled holes was longer as is clearly shown. Prior to pull testing, the encapsulated resin sections, providing additional anchorage from the reamed section of the holes were chipped away and removed, ensuring that the bolt anchorage did not extend beyond the mouth of the encapsulation in the hole. The length of the resin sausages used for bolt installations shown in Figure 37 were between 230 and 250 mm.

In maintaining the encapsulation length on the five bolts constant, the results of the pull tests demonstrated that over drilling had significant impact on the anchorage performance of the installed bolts. Figure 38 shows the photographs of the post pull test bolts, which showed variations between the lengths of resin encapsulation marks along the bolts. It is clear from this batch of pull testing that over drilling improves the performance of the bolt anchorage.

5.3. Summary of the Laboratory SEPT

The laboratory overhead pull testing study has demonstrated that over drilled bolts performance were better than those bolts installed in bore holes with no over drilling. By maintaining the bolt anchorage length constant, the effectiveness of the over drilling, in housing excessive resin shredding above the bolt becomes obvious and this finding is in agreement with what was achieved from underground studies reported previously. Thus, consistent results can be achieved only by ensuring that the length of the resin encapsulations of the installed bolt is maintained constant. Also, 3/7 s installation time combination appears to be inferior to 5/5 sec.
Figure 36a - Over drill v no over drill pull test load-displacement graphs

Figure 36b - Over drill v no over drill pull test values in kN

Figure 37 - 230-250 mm resin cartridges used for Batch four bolts installation

Figure 38 - Post pull test Batch four bolts. Yellow Arrow indicate 50 mm over drill bolts
6. RESIN STRENGTH PROPERTIES

There is no Australian standard for evaluating mechanical properties of resins or cementitious grouts used for bolt or cable installations. Therefore, there is no uniform method for testing resins for strength. Depending on the country of origin, based on various standards, manufacturers invariably use different specimen shapes and sizes to determine the strength properties of the resin or grout. Currently three known standards available and are likely to be used in Australia for strata reinforcement system components evaluations, and in particular for resin and grout strength. They are:

2) American Standard for Testing Materials (ASTM) F 432-10: Standard Specification for Roof and Rock Bolts and Accessories; and
3) South African Standard SANS1534.

There appears to be a divided loyalty and preferred practices in testing or determining the strength of resin with regard to sample shape and size. Irrespective of the resin setting time (fast, medium and slow set), the Uniaxial Compressive Strength (UCS) property is determined either by using 40 and 50 mm cubes, or cylindrically shaped samples, with varying diameters of 20, 30, 42 and 54 mm. In general, 40 mm cubes and 20 mm diameter cylindrical size appears to be the most desirable sizes for testing resins, depending on the resin setting time. The 40 mm cube is used for both fast and slow-setting resins, however, the 20 mm diameter cylindrical shapes of length to diameter ratio of 2 was used for fast-set resin testing. This ratio is generally used for testing composite material such as concrete, although at much larger diameters. Normally the length to diameter ratio of between 2.5 -3.0 is recommended for testing rocks in compliance with the suggested method for determining the UCS and deformability of rock material of International Society of Rock Mechanics (1979). While this is true for rock sample preparation by coring, nevertheless, this may not be a desirable shape for preparation of samples for composite materials.

The shape of the sample is not a major issue for resin and grout samples preparation using slow setting resin. Both cube/prism and cylindrical shapes can be prepared and tested individually by mixing mastic and catalyst hardener at a leisurely pace. The situation becomes more difficult, when preparing samples from fast setting resins, which typically have a setting time of 15-20 s. Accordingly, a new approach as proposed in this report should allow several samples to be cast simultaneously from one fast setting resin mix batch, thus reducing sample property variability.

- Uni-axial compressive Strength,
- Modulus of Elasticity in compression
- Shear Strength,
- Creep or Rheological Properties

6.1. Uni-axial Compressive Strength

Traditionally resins are tested for compressive strength, using cube prism samples. The British standard BS 7861- part 1 Annex (M) and part 2 Annex (G) for testing resin grout uses prisms 12.5x12.5x50 mm in size with respect to the resin set time. Opinions vary with respect to the shape and size of the samples tested. According to BS 1881: part 4: 1970, the strength of a cylinder is equal to four fifth of the strength of a cube, however experiments have shown that there is no simple relation between the strengths of the specimens of the two shapes. Generally resin manufacturers tend to determine the UCS values of the resin by testing 40 mm cubes, similar to the recommended methods for testing composite materials. It is a well-known fact that the strength values obtained by testing cube samples tend to be on the higher values than the cylindrical samples. Also, the strength values tend to vary significantly, irrespective of the sample shape and size as the samples are generally cast individually.
The recent approach in sample preparation as reported by Aziz, et al., (2013) has demonstrated that the consistency of the UCS values can be improved if prepared samples are obtained from one mix (discussed later). Therefore, it is easier to test resins of different setting speeds in a unified selected manner.

### 6.2 Elastic Modulus of Elasticity

The modulus of elasticity determination of the resin as prescribed in BS 7861: part 1: 1996, recommends that a prism of L/D of 4 be subjected to a controlled compressive load. The axial and lateral strain to be monitored by four strain gauges mounted on the samples, or by using other means of monitoring the axial and later deformation of the tested sample, such as linear variable differential transformers LVDTs, compressometers, optical devices or other suitable measuring devices. The tested sample is subjected to cyclic loading /unloading and the elastic modulus is the mean of the three-secant moduli measure between two levels of the applied load. This method of determining the E value of resin can also be obtained from the straight line extrapolation of the 20-60 kN or 40-80 kN range of the load-displacement profile range (Figure 25). However, E values by this method may not yield E values comparable to the recognised values as suggested by various standards for resins, grouts and rocks as the value of E for the 40 kN Load range will be equivalent to the sample compression. However the calculated value from this approach is markedly outside the values obtained from other more credited methods. The E-values were determined using the following mathematical relationships as:

\[
E_t = \frac{\partial \sigma^*}{\partial u^*} \quad (1a)
\]

\[
E_s = \frac{\sigma^*}{u^*} \quad (1b)
\]

\[
E_r = \frac{1}{du^*} \quad (1c)
\]

Where;
- \(E_t\): tangent elastic modulus,
- \(\sigma^*\): half of the peak stress value
- \(u^*\): displacement at half of the peak stress
- \(E_s\): tangent elastic modulus
- \(E_r\): 40 kN range elastic modulus
- \(Du^*\): displacement at 40 kN load range (i.e. between 20 kN and 60 kN).

### 6.3. Punch shear test

Table 7 lists various apparatus used for testing of resins and composite material in shear (Aziz, et al., 2014). The testing for shear falls into two categories, direct and indirect methods. All listed methods are applicable for testing resins, but the resin characteristics, time and effort restrict their selection for any particular resin type. Punch shear test method is most suited for testing resin. The punch shear box apparatus is shown in Figure 39. This methodology of shear strength determination is currently advocated by the South African Standard for testing of resins and grouts (SANS 1534:2004), and it has currently been used by various resin manufacturers in Australia. Experience has shown that punch shear test is most suited for testing of resin particularly the fast setting resins. The test is carried out using a thin (3mm) disc-shaped specimen, which is slotted in the middle of the punch shear box (40 mm in diameter and 30 mm high) fitted with a hollow slot of the same diameter as the 12.5 mm diameter punch as shown in Figure 26. Full circle discs or a quarter circle segments can be used with this punch test apparatus.

The shear strength is determined using:

\[\tau = \frac{F}{\pi T D}\]

\(\tau\): the shear strength of the tested sample

\(F\): failure load

\(T\): disc thickness

\(D\): Punched disc diameter
Based on experiences, the punch shear box test appears to be superior to other tests because of:

1. The ability to prepare a number of samples in very short period of time and produce a number of samples from one resin mix, thus allowing repetition of the test results for confirmation.
2. It requires a small amount of resin preparation for testing, hence mixing time is not a problem.
3. It gives consistent results for different period of times, and
4. It is fast testing method.

The punch shear box can be used as a suitable tool to assess the consistency and quality of the resin samples prepared for various strength properties (UCS, E). This can be achieved by a simple comparison of the shear strength values obtained from testing of 3 mm thick samples.

Table 7 - Laboratory methods of testing of shear strength of resin and grout

<table>
<thead>
<tr>
<th>Method</th>
<th>Type</th>
<th>Procedure</th>
<th>Comments</th>
<th>Apparatus</th>
</tr>
</thead>
<tbody>
<tr>
<td>Direct</td>
<td>Direct shear</td>
<td>Resin sample in plaster or cement and shear the sample to failure peak and residual shear strength</td>
<td>Difficult to match resin strength with the cast medium and testing is a slow process.</td>
<td></td>
</tr>
<tr>
<td>Direct</td>
<td>Single shear</td>
<td>The sample is clamped on the specimen holder and a shear force is applied perpendicular to the curved surface through a sharp edged platen. The shear strength is the force at failure divided by the area of cross-section of the failure surface</td>
<td>Not commonly used</td>
<td></td>
</tr>
<tr>
<td>Indirect</td>
<td>Triaxial test</td>
<td>The specimen is enclosed in an airtight flexible membrane; confining pressure is applied and held constant during the test by means of a cell fluid. Apply axial load/hence stress until the sample fails. Test yields, UCS, Angle of Friction, Shear angle, failure angle</td>
<td>Good method of determining the shear strength of rock/resin; Requires expensive equipment, Difficult to do the test, slow, and time consuming</td>
<td></td>
</tr>
<tr>
<td>Indirect</td>
<td>Double shear</td>
<td>Lateral shearing of the sample with the samples ends supported. The specimen is sheared along two parallel planes. Shear strength = sheared failure load divided by twice the sample cross section area</td>
<td>Can be used for shear testing of 90 mm long and 30 mm diameter samples. Yields good results but require great quantity of resin samples cast</td>
<td></td>
</tr>
<tr>
<td>Indirect</td>
<td>Punch shear</td>
<td>Shear strength carried out over a very short period of time</td>
<td>Easy to cast discs for testing. Several punch tests can be carried out from one large disk. Allows testing for shear strength over several weeks.</td>
<td></td>
</tr>
</tbody>
</table>
6.4. Rheological Properties (Creep)

Creep study was carried out to investigate the strain time dependency. The recommended approach to determine resin creep properties is similar to that used for determining $E$ values. According to BS 7861-1 (1996), the sample is usually loaded at a stress rate of $0.75 \pm 0.25 \text{ (N/mm}^2\text{)}\text{s}$ to a load of 5 kN for fast and medium set resins or 20 kN for slow set resin and the load is maintained constant for a duration of 15 min. The resin strain is monitored between 0.5 min and 15 min. After 15 min, the load is removed completely. The resin creep must not be more than 0.12 %, when the sample is tested after 24 hours of casting.

7. Experimental Procedure

7.1. Sample Preparation

Chemical resin samples tested for strength properties evaluation were prepared from Orica resin mastic and hardener (catalyst) scraped from the mine supplied sheathed capsules. Figure 40 shows a mine supplies resin capsule having its mastic and catalyst being collected for strength testing. Preparation of competent samples is an important aspect of testing resin samples. The consistency of the testing results was dependent on the quality of the cast resin. Resin setting time was the deciding factor in preparing competent and uniform textured resin.

The methodology of preparing resin samples was by manually mixing and casting of samples individually, particularly for fast setting resins. This method is inevitably leads to less uniform sample composition and wider scatter of results. Additional drawback of casting sample by manual mixing and pouring include:

- the difficulty of removing the air bubbles from the sample, unless the sample is mechanically vibrated,
- Non-uniform composition of the sample mixtures as each sample has to be mixed and poured separately.
- One side of the cube sample remaining rough, which could eventually influence the test results, and
- Mixing of the resin in the mould may not be uniform, unless the mixer is skilled.
An alternative approach was trialled to produce several samples from a single resin/mastic mix. This was based by mechanically mixing a relatively large quantity of resin/mastic resin in one container using a paint mixer mounted on to a hand held drill. Two ways were possible to cast resin in a number of readily prepared moulds by either, pouring mixed resin into moulds as shown in Figure 41, or forcing a prepared mould bundle into the resin mix Figure 42. The forcing methods was suitable for both cylinder and cube moulds.

Once all the moulds are filled or submerged in the resin mix, it was left to harden. The hardened cast samples were individually removed from the mould by gentle tapping. Alternatively, the whole resin block was split or broken, separating the plastic moulds apart the samples were extracted from each mould. This was then followed by the extraction of the samples out of their plastic moulds. Figure 41 shows the sequence of resin mixing and sample casting by forcing moulds into the mixed resin. The dimensions of sample cast can be varied as required. It is worth noting that by forcing moulds as a bunch into readily mixed resin must be accomplished as quickly as possible, because of the limited time available before the resin hardens. All plastic moulds and mixing containers were readily lubricated with appropriate grease or lubricant spray to allow the cast sample to be easily freed from the mould.

Irrespective of the sample shape and size, the quality of the cast samples were found to improve with proper vibration to remove trapped air bubbles and removes any remaining voids. Typical samples prepared from multi sample casting are shown in Figure 41J. It should be also be possible to cast cube samples in similar manner (Figure 41K). Further modifications to samples casting were subsequently made to exclude unmixed resin, which is normally accumulated in the periphery of the mixing container. Details of the new mixing and casting assembly are shown in Figure 43. Figure 43D shows variations in the quality of mixing resin.

In compliance with the established standard requirements for sample end smoothness, the samples were extracted from moulds; their ends were cut perpendicular to the sample axis and then subsequently lapped for smoothness prior to testing,
Figure 41 - casting resin samples in bulk by pouring mixed resin into moulds
Figure 42 - The alternative method of forcing mould bunch into the mixed resin container

Figure 43 - Double layered container for mixing chemical resin mechanically and variations in resin quality due to differing mixing techniques
7.2 Uni-axial Compression Strength

Table 8 shows the UCS results of seven 30 mm diameter resin samples from one batch. It is clear that the quality of the samples and the test results have demonstrated the credibility of the new method of preparing resin samples. The average UCS value of the seven tested samples was 53.16 MPa, with a standard deviation of 0.47 and a coefficient of variation of 0.88%.

Table 8- The UCS test of fast-setting resin cast 30 mm diameter samples

<table>
<thead>
<tr>
<th>Sample</th>
<th>Sample Age (days old)</th>
<th>Sample Length (mm)</th>
<th>Failure Load (kN)</th>
<th>UCS (MPa)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>4</td>
<td>78.52</td>
<td>36.8</td>
<td>53.88</td>
</tr>
<tr>
<td>2</td>
<td>4</td>
<td>78.56</td>
<td>36.1</td>
<td>53.08</td>
</tr>
<tr>
<td>3</td>
<td>4</td>
<td>78.29</td>
<td>35.6</td>
<td>52.41</td>
</tr>
<tr>
<td>4</td>
<td>4</td>
<td>78.48</td>
<td>36.7</td>
<td>53.38</td>
</tr>
<tr>
<td>5</td>
<td>4</td>
<td>78.55</td>
<td>36.3</td>
<td>52.99</td>
</tr>
<tr>
<td>6</td>
<td>4</td>
<td>78.12</td>
<td>36.2</td>
<td>53.45</td>
</tr>
<tr>
<td>7</td>
<td>4</td>
<td>78.29</td>
<td>36.0</td>
<td>52.91</td>
</tr>
</tbody>
</table>

Average: 53.16, SD: 0.43 and CV: 0.8

A round 100 chemical resin samples of various shapes, sizes, set time, cure time and age were tested for UCS values. Figure 45 shows the load-compression displacement profiles of various shaped samples prepared from the same set time resin (90 sec gel time resin and catalyst removed from a capsule). The samples tested were one day old. Variations in samples shape and sizes are clearly shown in the figure.

Figure 46 shows bar charts of the variation in average UCS values with changing sample shape and size of one day old cast samples. The ratio between cube strength and cylinder strength varied from 1.10 to 1.30. The high cube UCS value is attributed to friction between the platens of the compression machine and the specimen ends creating relatively higher confinement (triaxial compression) than cylindrical specimens of the H/D ratio 2 as demonstrated in Figure 47. The comparatively high values for cubes compared to cylinders were also reported with cementitious grouts (Minders, et al., 2002). Figure 48 shows the changes in resin strength with age, which is expected. Figure 49 shows the variation in resin strength with respect to sample H/D ratio for cylindrical samples. As expected, the strength of the sample was influenced by the sample size and this is similar to rocks and cement grouts (Neville, 2069; Minders, et al., 2002). The comparison between samples strength made from new resin that from stored resin (2 month old resin) is shown in Figure 50. It is observed that a higher uniaxial compressive strength was obtained by using fresh resin in comparison to stored resin. The strength values of the resin used in bolt encapsulation was influenced by the shape and size of the samples for both 20 mm and 30 mm diameter samples, L/D=2.

The procedure for sample preparation and testing for UCS is described in Section 4.5.
Figure 44 - Casting cube samples in cubical mould

Figure 45 - Load/compression profiles of various shaped samples prepared from one day old resin mix

Figure 46 - Bar charts of the UCS values with changing sample shape and size for one day old cast samples
Figure 47 - Variations in UCS values between cube and cylinder resin samples (Orica slow setting resin - 90 secs setting time). Note the consistency of the test results.

Figure 48 - Variation in resin strength with sample cure time for 30 mm diameter 2:1 ratio cylinder samples.
Figure 49 - Variation in UCS values with respect to sample height / diameter (H/D) for slow setting resin cylindrical samples

Figure 50 - Variation in resin UCS values between new supplied and stored (old) resins, for both 20 mm and 30 mm diameter samples, L/D=2

7.3. Modulus of elasticity (E Value)

Three methods, namely 40 kN range, tangent and secant modulus were used to make a comparative study. The use of 40 mm cube samples simplifies the determination of E value as the value of E for the 40 kN load range will be equivalent to the sample compression. However the calculated value from this approach is markedly outside the values obtained from other more credited methods. Samples were subjected to either monotonic or cyclic loading. In monotonic loading as shown in Figure 1, the axial load was increased in a constant rate capturing elastic, hardening and softening behaviours. In cyclic loading conditions, however, samples were exerted to an incremental axial load until reaching 80% of its peak load strength followed by an unloading process, whereby the axial load dropped to the minimum designated value (i.e. 1 kN). This trend was pursued for three cycles and afterward the samples were loaded similar to that of monotonic loading as illustrated in Figure 2. E-values were determined as described in Equation 1 by taking average of the first three cycles of loading.
Figure 51 – A typical monotonic loading scheme subjected to the sample

Figure 52 – A typical cyclic loading scheme subjected to the sample

Figure 13 shows the comparison between E-values obtained through different ways for resin cubic samples with various curing time ranging from 7 to 21 days. E-values determined by the 40 kN range (manufacturer recommended) are generally higher than those obtained from ISRM (International Society of Rock Mechanics) recommended methods such as tangent and secant modulus for various curing intervals. Also, E-values increased as the resin curing time increased from 7 to 21 days.

Figure 14 compares the E-values determined from the strained gauged samples and specimens without strain gauges. It is observed that the data extracted from strained gauged samples provide higher Elastic modulus when compared to samples without strain gauges. It should be noted that the E values obtained using strain gauges are restricted to the middle section of the tested sample and not the entire length of the sample under compression, hence the variation in E values reflects on the condition of testing and is in line with various test standards indicated previously. Using strain gauged specimens as
shown in Figure 5, in which the strain gauge is precisely installed in the middle of the tested sample, enables the direct measurement of the displacement without the end effect. The comparison between the E-values of cubic and cylindrical samples for different curing time is shown in Figure 15. It is concluded that the cubic samples exhibit higher elastic modulus values in comparison to cylindrical specimens various curing time. However, this aspect involves further study. See section 5 for the suggested procedure for testing and determining E values of resins samples.

---

**Figure 59** - Comparison between the E-values obtained through different ways for resin samples with various curing time ranging from 7 to 21 days

**Figure 60** - Comparison between the E-values determined from the strain gauged samples and specimens without strain gauges
The comparison between $E$-values of cubic and cylindrical samples for different curing time is shown in Figure 15. It is concluded that the cubic samples bear more elastic modulus values in comparison to cylindrical specimens for different curing time.
In Figure 8, the influence of sample dimension in the secant elastic modulus is compared. The data trend indicates that the value of secant stiffness increases with increasing the sample size.

Figure 9 compares the British standard with the one introduced in this study using strain gauged samples. The British standard gives a higher value for the secant elastic modulus when compared to the proposed standard.
7.3. Punch Shear Test Results

Using the punch shear box shown in Figure 2 a series of punch shear tests were undertaken to study the shear strength of a particular resin. Each 65 mm diameter, 3 mm thick disc was cast using the new resin casting mould shown in Figure 2. Four shear tests were obtained from each disc cast. Table 9 shows typical results of punch tests carried out on several segments of one disc sample of the Orica fast setting resin, which is scraped from the resin capsules supplied to a designated mine. A number of tests from a single or several large samples prepared using the newly designed casting moulds demonstrated the ease with which several tests can be carried out over a short time and with consistency of the results. Figure 16 shows the bar chart of variations in the average values, indicating the increase in average shear values with sample cure time, similar to UCS values. Figure 17 shows the variation of shear strength values between Mix and Pour and scraped slow setting resins respectively.

Using the punch shear box a series of punch shear tests were undertaken to study the shear strength of a particular resin. Table 6 shows typical results of punch test carried out on Minova/Orica fast setting resin, which is scraped from the resin sausages supplied to a designated mine. The value of shear punch test was determined by using the following equation;

\[ \tau = \frac{F}{3.142 \times T \times D} \]

F = applied load, \( \tau \) = shear strength, T = Sample thickness and D = Punch diameter

The next task is to expand shear testing programme to include a comparative testing of the resin using different tests to achieve a universal acceptance of the chosen technique by the mining Industry. This programme of study will include various resin types.

Figure 65 – Comparison between the proposed model and British standard in determination of secant elastic modulus
Table 9 - Shear strength values of resin samples tested using punch shear test. The test results are with respect to the samples cure time of 1, 7 and 14 days

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<thead>
<tr>
<th></th>
<th>MN</th>
<th>T (m)</th>
<th>D (m)</th>
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<th>( \tau ) (MPa)</th>
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Figure 66 - Average shear strength values for various cast samples cure time

Figure 67 - Variation in resin shear strength values between new supplied and scraped resins for various curing periods
7.4. Creep tests

Creep study was carried out to investigate the strain time dependency. Different resin samples were subjected to 50 kN of axial load for duration of 15 min and displacement was recorded using both strain gauge and Instron machine. A typical axial load measured upon elapsed time is shown in Figure 10.

![Figure 10 - Typical measured axial load against loading time](image)

Strain was then calculated in four time steps as 10 sec, 5 min, 10 min and 15 min. Creep is defined as the difference between the strain in 10 sec and 15 min in percentage as shown in Figure 11.

![Figure 11 - Creep curve measured in four time steps](image)

Figure 12 compares the effects of sample type on the creep resistance. It is evident that the cubic sample shows the highest resistance against the constant load of 50 kN in comparison to rectangular and cylindrical samples.
As discussed in elastic modulus section, the value of strain and therefore creep are affected by the measurement device whether strain gauge or Instron machine due to the end effect. Figure 13 shows comparison between the creep values obtained using samples with strain gauge and without strain gauge.

It is clear from Figure 13 that samples without strain gauges underestimate the creep in comparison to the strain gauged specimens.

The creep study was further extended according to the British standard. The creep value for a rectangular sample with dimensions of 12.5*12.5*50 mm³ subjected to 5 kN of axial load was drawn to be 0.41%. This is 0.3% higher than the value obtained incorporating the proposed standard.
7.5 Summary
The new method of casting multiple samples in bunch represents a convenient method of preparing samples for strength testing. The prepared samples have been found to be of uniform composition and yielded consistent results. The proposed method of casting samples is:

- fast as no additional time is required for repeated casting;
- sample sides are uniform as the moulds are not split axially;
- can be applied to cylinder as well as cube sample preparation;
- reduces the formation of voids and the composition of the cast sample.
- strength values determined for various resins are consistent and repeatable, thus the proposed methodology of resin casting and samples preparation represent a suitable approach in testing different types of resins, thus allowing the establishment of a creditable testing procedures and establishment of a credible Australian Standard.
8. PROCEDURES FOR TESTING STRENGTH PROPERTIES

8.1 Suggested Method for Determination Uniaxial Compressive Strength of the Resin/Grout Used for Rock Bolting Installations

1. Scope

This method of test is intended to measure the uniaxial compressive strength of chemical resins or cementitious grouts used for rock bolting. The test is mainly intended for strength classification and characterisation of resins and grouts. The test also describes the manner in which how the test results are interpreted with respect to the test sample shape and size.

2) Apparatus

(a) A refrigerator to store and maintain chemical resin at a temperature 4.0°C ± 1.0°C.
(b) A suitable compression testing machine for applying and measuring axial load to the resin and grout specimen.
(c) A spherical seat, to permit axial load application on the tested sample. The spherical seat should be placed on the upper end of the specimen. It should be highly lubricated with mineral oil so that it locks after the dead weight of the cross head has been picked up. The specimen, the platens and spherical seat shall be accurately centred with respect to one another and to the loading machine. The curvature centre of the seat surface should coincide with the centre of the top end of the specimen.
(d) Steel platens of the same shape as the tested sample. The steel plates should have sufficient strength and a Rockwell hardness of not less than HRC58, comparable to the strength that is used for normal rock UCS testing. The width of the steel plates should be + 2mm larger than the specimen side in case the tested sample is a cube. Surfaces of the discs should be ground and their flatness should be better than 0.005 mm

3) Procedure

a) The following procedure is applied to testing of cylindrical, cube and prism samples. The recommended dimensions of the samples tested are as follows;
   • Cube: 40 mm side,
   • Prism: base 40 mm² and height 80 mm (H/W=2), and
   • Cylinder: 40 mm diameter (size BX) and L/D =2.

Irrespective of the sample shape, it is recommended that the ends of the specimen shall be flat to 0.02 mm and shall not depart from perpendicularity to the axis of the specimen by more than 0.001 radian (about 3.5 min) or 0.05 mm in 50 mm.

b) The sides of the specimen shall be smooth and free of abrupt irregularities and straight to within 0.3 mm over the full length of the specimen. If cubes are tested it is preferable to load the samples at right angle to the position at which it is cast, thus avoiding irregularities.

(c) The use of capping or end surface treatment other than machining is not permitted.

(e) The sides of the tested specimen shall be measured to the nearest 0.1 mm.

(f) Load on the specimen shall be applied continuously at a constant stress.

(g) Load on the specimen shall be applied continuously at a constant stress such that failure will occur within 5-10 min of loading, alternatively the stress rate shall be within the limits of 0.5-1.0 MPa /s.

(h) The maximum load on the specimen shall be recorded in “N”, KN, or MN to within 1%.
(i) The number of samples tested should be determined from practical consideration, but at least six samples are preferred. Discard the sample which is not in accordance to other samples results.

4) Calculations and Reporting

The Uniaxial compression Strength of the resin/grout specimen shall be calculated by dividing the maximum load by the specimen original cross-sectional area. The final USC value will be the average value of the number of samples tested.

8.2 Suggested Method for Determination Shear Strength (Punch Shear Test)

1) Scope

This method of test is intended to measure the shear strength of chemical resins or cementitious grouts used for rock bolting. The test is mainly intended for strength classification and characterisation of resins and grouts. The test describes the manner in which how the test results are interpreted with respect to the test sample shape and size.

2) Apparatus

(a) A refrigerator to maintain chemical resin at a temperature 4.0 °C ± 1.0 °C.
(b) A suitable resin/grout mixing container.
(c) A suitable apparatus /mould to prepare chemical resin/grout for casting sample for punch shear test. Details of the sample preparation are as discussed in the main body of the ACARP report, section 4.3.3 on Punch Shear test (see opposite Figure). The recommended sample thickness, to be tested, shall be 3 mm ± 0.01.
(d) A punch shear box, similar to the South African standard apparatus for testing resins and grouts (SANS 1534:2004) (See figure opposite. This tool assembly comprises (1) a punch of diameter of 12.5 mm and (2) a die of diameter of 12.70mm. This is the most practical punch shear box tool and it has currently been used by various resin manufacturers in Australia.
(e) A suitable compression testing machine for applying and measuring axial load to the resin/ grout specimen.
(f) A precision Vernier, capable of reading down to 0.01 mm resolution. The thickness of the test sample should be measured at several points to the nearest 0.05 mm.

3) Procedure

(a) Load on the specimen shall be applied continuously at a constant rate of load application at 1.0 mm /min. The rate of loading should be such that the failure will occur between 20 sec and 45 s.
(b) The maximum load on the specimen shall be recorded in N, kN or MN to within 1%
(c) The number of samples tested shall be a minimum of six samples. Discard the sample with test result not in agreement with the average value of other tested samples.

4) Calculations and report of the results

(a) The shear strength of the tested sample is calculated from the equation:

\[ \tau = \frac{\Phi}{\pi T \Delta} \]

\( \tau \): Shear strength of the tested sample
\( \Phi \): Failure load
\( T \): Disc thickness
\( \Delta \): Punched disc diameter
b) Date of testing
c) Tested sample age (date of casting and testing).
d) Test duration and stress rate
e) Observations on the failed sample (cavities and air bubbles, etc)

8.3- Suggested Method for Determining the Modulus of Elasticity /Young Modulus of the Resin/Grout used for Rock Bolting Installations

1. Scope and introduction

This method of test us intended to determine stress-strain curves and Young's Modulus (E) and Poisson’s ratio in uniaxial compression of a resin or grout specimen of regular geometry.

Two methods are used to determine E value of resin; (a) the fixed 40 kN load range method, and (b) the mid height E value measured using strain gauges mounted at the mid-height sample. The sample used has height to width ratio of two. Both methods are described here and the results are compared.

2. Apparatus

(d) A refrigerator to store and maintain chemical resin at a temperature 4.0 °C ± 1.0 °C.
(e) A suitable compression testing machine for applying and measuring axial load to the resin and grout specimen.
(f) A spherical seat, to permit axial load application on the tested sample. The spherical seat should be placed on the upper end of the specimen. It should be highly lubricated with mineral oil so that it locks after the dead weight of the cross head has been picked up. The specimen, the platens and spherical seat shall be accurately centred with respect to one another and to the loading machine. The curvature centre of the seat surface should coincide with the centre of the top end of the specimen.
(g) Steel platens of the same shape as the tested sample. The steel plates should of sufficient strength and a Rockwell hardness of not less than HRC58, comparable to the strength that is used for normal rock UCS testing. The width of the steel plates should be + 2mm larger than the specimen side in case the tested sample is a cube. Surfaces of the discs should be ground and their flatness should be better than 0.005 mm
(h) Electrical strain gauge, linear variable deferential transducers, compressmeters, optical devices or other suitable measuring devices. The devices used should have sensitivity of the order of 5 x 10^-6.
(i) Both axial and lateral strains should be determined within an accuracy of 2% of the reading and a precision of 0.2 % of full scale. If Electrical strain gauges are used, the length of the strain gauges should not encroach within 0.5 length or height of the specimen width.
(j) A data logger or any suitable recording devices to record the applied loads and deformations.

3. Procedure

(a) The following procedure is applied to testing of cylindrical, cube and prism samples. The recommended dimensions of the samples tested are as follows;
   - Cube: 40 mm side,
   - Prism: base 40 mm² and height 80 mm (H/W=2), and
   - Cylinder: 40 mm diameter (size BX) and L/D =2.

Irrespective of the sample shape, it is recommended that the ends of the specimen shall be flat to 0.02 mm and shall not depart from perpendicularity to the axis of the specimen by more than 0.001 radian (about 3.5 min) or 0.05 mm in 50 mm

59
b) The sides of the specimen shall be smooth and free of abrupt irregularities and straight to within 0.3 mm over the full length of the specimen. If cubes are tested it is preferable to load the samples at right angle to the position at which it is cast, thus avoiding irregularities.

c) The use of capping or end surface treatment other than machining is not permitted.

d) The sides of the tested specimen shall be measured to the nearest 0.1 mm.

e) Load on the specimen shall be applied continuously at a constant stress rate such that failure will occur within 5-10 min of loading, alternately the stress rate shall be within the limits of 0.5 -1.0 MPa/s.

f) The maximum load on the specimen shall be recorded in “N”, KN, or MN to within 1%.

g) The number of samples tested should be determined from practical consideration, but at least six samples are preferred. Discard the sample test results, which is not significantly different the results of others consistent values

4. Calculations

(a) Axial strain ε_a and lateral strain ε_d can be recorded directly from strain indicating equipment or calculated from Deformation readings depending upon the type of instrumentation used.

5. Reporting of the results

5.4: Suggested method of determination creep properties of resin and grouts

1) Scope
This method of test is intended to measure the creep properties of chemical resins or cementitious grouts used for rock bolting. The test is mainly intended for stiffness classification and characterisation of resins and grouts. The test describes the manner in which how the test results are interpreted with respect to the test sample shape and size. Tests pieces of a defined geometry are subjected to a defined compressive force, and deformation is recorded against time.

2) Apparatus

a. A refrigerator, to maintain chemical resin at a temperature 4.0 °C ± 1.0 °C.

b. A suitable resin/grout mixing container.

c. A suitable apparatus /mould to prepare chemical resin/grout for casting sample size as appropriate for testing the resin/grout type.

d. A suitable compression testing machine for applying and measuring axial load to the resin/ grout specimen.

e. Electrical strain gauge, linear variable deferential transducers, compressometers, optical devices or other suitable measuring devices. The design should enable the mean of two axial strain measurements, equally spaced, to be determined for each increment of load. The devices should be robust and stable, with strain sensitivity of the order of 5 x 10^{-6}.

If dial micrometres or LVDTs are used for measuring axial deformation, these devices should be graduated to read in 0.002 mm units and accurate within 0.002 mm units and accurate within 0.002 mm in any 0.02 mm range and within 0.005 mm in any 0.25 mm range as recommended by the established standards BS7861:Part 1 (1996), and ASTM. The dial micrometre or LVDTs should not encroach within 15 mm of the specimen ends, unless measurements are being made indirectly, between the machine platens.

Both axial and lateral strains should be determined within an accuracy of 2% of the reading and a precision of 0.2 % of full scale. If Electrical strain gauges are used, the length of the strain gauges should not encroach within 0.5 length or height of the specimen width. Alternatively, the length of the gauges over which axial strains
are determined needs to be at least 20 mm and the gauge should not encroach within 15 mm of the specimen ends as recommended by BS7861:Part 1 (1996).

f. A data logger or any suitable recording devices to record the applied loads and deformations.

g. A precision Vernier, capable of reading down to 0.01 mm resolution. The thickness of the test sample should be measured at several points to the nearest 0.05 mm.

3) Procedure

a) Specimen preparation: prepare the test specimens, including the conditioning, proportioning and mixing of materials and the conditioning, and filling of the mould in accordance with the appropriate sample preparation and casting moulds. Samples should be mixed and cast in moulds at a laboratory temperature of 20°C ± 5°C. Take five specimens from the same mix.

Irrespective of the sample shape, it is recommended that the ends of the specimen shall be flat to ± 0.02 mm and shall not depart from perpendicularity to the axis of the specimen by more than 0.001 radian (about 3.5 min of arc) or 0.05 mm in 50 mm. The dimensions of the samples used will be dependent on the resin setting/gelling time.

b) The sides of the specimen shall be smooth and free of abrupt irregularities and straight to within ± 0.3 mm over the full length of the specimen. If cubes are tested it is preferable to load the samples at right angle to the position at which it is cast, thus avoiding irregularities.

c) Wipe clean the bearing surfaces of the testing machine and of any auxiliary platen. Carefully place the test specimen on the lower machine platen and centre it in such a manner that the load is applied axially.

d) without load being applied record the strain gauge reading. At a strain rate of 0.75 (n/mm²)/s ±0.25 (N/mm²) record and then maintain a load according to the sample size shown in Table 10 and record the change in strain at 0.5, 1.0, 5, 10, and 15 min. After 15 min remove the load completely.

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<tr>
<td>Medium set</td>
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<td>Slow set</td>
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4) Results

From the original (unloaded) gauge length determine the specimen gauge length 30 s after application of the applied load. Then determine the difference in strain for each subsequent time interval up to and including 15 min. Calculate the percentage change in strain with time. Minimum number of samples tested should be not less than five (5) samples. Discard the highest and lowest results. Calculate the mean results from the reaming sets of values and plot a graph of percentage strain against time.

The resistance to creep is deemed to be the difference in percentage strain determined at 0.5 and 15 min following application of the load.

5) Calculations and reporting of results
SUGGESTED PROCEDURE FOR SHORT ENCAPSULATION PULL TESTING (SEPT) OF BOLTS

1. Scope

This method of test is intended to determine the load bearing capacity of the short length of resin/grout encapsulated bolt commonly called Short Encapsulation Pull Testing (SEPT) carried out at the desired locations in a mine or in laboratory. Two methods of SEPT are practiced, and procedures described shall address both alternatives. They are:

a) The conventional approach, and
b) Sacrificial top of bolt approach, which is an alternative method of SEPT that require a specialised bolt preparation as shown in Figure 72. Known as “Split BOLT SEPT” the method is suitable for testing installations with spin-to stall installations.

The SEPT test is mainly intended for the performance characterisation of bolt installation in different mediums and locations where the test conditions vary.

2. Apparatus

1. A suitable drill machine which could be; (i) a hand held roof bolter or (ii) a hydraulically operated bolter mounted on the heading machine or a self-reticulated roof bolter.

2. Drill tool (bit, rod and reamer). Drill tool should be able to accommodate drilling with and without reamer mounted on the drill string.
   a. Reamed hole method: A combination of drill, rod and a reamer is known as “inline reamer”. The reamed hole method best guarantees correct bond length for SEPT.
   b. Drill and ream: The hole is drilled first to the predetermined depth/height. The hole is then reamed separately to the given height, leaving the top length for bolt encapsulation.

3. Resin/grout capsule: The capsule should be equal to the non-reamed ‘bond length’ portion of the hole

4. A suitable length of the test bolt. The selected bolt should be of sufficient length to ensure that the encapsulated section of the bolt shall be installed about 200-300 mm inside the rock mass or composite medium, and have sufficient length protruding outside the medium to accommodate load cell, hydraulic ram, nuts and washers. An 800 mm long bolt shall be of sufficient length to conduct SEPT in rock mass with 200-300 mm encapsulation length anchored 200 mm some 200 mm from the borehole mouth, with the 200 mm reamed lowered end.

5. A hollow load cell of adequate capacity to monitor the pull load,

6. A hydraulic ram for pulling the bolt out.

7. A hydraulic jack to pump the ram. The hydraulic Jack could be a simple manually operated unit or electrically powered pressure pack, depending on the test environment.

8. A hydraulic pressure monitor. A calibrated force gauge (tonnes or kN) shall be used with the accompanying hydraulic jack of known ram area, the small increment should not be larger than 1 t. All hydraulic equipment must comply with the NSW Department of Mines “MDG41” guidelines, and site specifications. Alternatively, approved battery/electrically powered readout units shall be used, as dictated by the test environment.

9. A displacement measurement tool: This could be one of the following:
   - A mechanical dial gauge mounted on roof/floor convergence strut or Pogo stick, with the top end attached to the end of the protruding bolt/extension (Figure 73). This arrangement will allow displacement to be read from the end of the bolt/extensions to the floor, directly below the axis of the bolt being pull tested. All practical efforts should be made to align the displacement measuring device axis with the axis of the bolt. In underground coal a dial gauge
accurate to 0.1mm is adequate, which eliminates the hazard of non-approved electrical apparatus in an underground coal mine

- A string potentiometer, suitable for nonhazardous environment, can be used as shown in Figure 74.
- A Linear Variable Deferential Transducer (LVDT) attached to a magnetic clamp shown in Figure 75.
  Both LVDT and potentiometers are suitable for both the laboratory study and also to nonhazardous sites.

- For spin and stall tests, split bolts are used for testing as shown in Figure 72.

3) Procedures

(3.1) Conventional SEPT

a) Calibrate and check equipment used for pull testing prior to use,
b) Select suitable length of bolts with nuts and washers. Ensure that one end of the tested bolt is threaded. Mark off the desired encapsulation length of the bolt, making sure that the encapsulated length is at the tip of the reamed lower section of the drilled hole. Normally the length of the bolt used for pull testing varies between 800 to 900 mm depending on the bolt end encapsulated length. Bolt encapsulation section should be installed higher up in the medium some 200-300 mm inside the medium or strata. Avoid installing bolt encapsulation section flush with the test surface, in order to prevent cratering of the medium during pulling out of the encapsulated bolt.
c) Avoid overreaming of the hole with respect to the length of encapsulation in the medium, as over-reaming may influence the rifling pattern of the encapsulated section of the drilled hole.
d) Remove the resin from the reamed section of the hole which might cause the bolt to bond or encapsulate an extra length of the bolt
e) Install the bolt in drill hole, taking particular care of maintaining constant drilling rate and drill RPM. Drill rate time refers to the bolt installation time, consisting of two components; spin to back, and spin at back. “Spin to back” is the time taken for the bolt being pushed up to the back of the hole and “spin at back” is set bolt spin time in the back of the hole.
f) Pull out the bolt by jacking it using the hydraulic ram. Measure both the applied load and displacement with the available measuring unit. Identify the displacement at peak load.
h) Pull the tested bolt out of the hole completely and examine the encapsulation length. Effective encapsulation length is the slickenside length, which may not necessarily be the full length encapsulation as shown in Figure 76. Determine the bond strength by dividing the pull load with slickenside section of the encapsulation length. Discard the test if the encapsulation does not show the clear evidence of shearing.
i) The type of applied ramming or jacking load and displacement measurements apparatus will be dependent on the test environment. When pull test is carried out in the field, the use of a dial gauge (accurate to 0.1mm) mounted on a bracket fixed on a roof pole or Pogo Stick and a hydraulic ram with a pressure readout unit may be sufficient as shown in Figure 74. A mechanical dial gauge;
  i. eliminates the hazard of non-approved electrical apparatus in an underground coal mine,
  ii. can be set to zero at 2 t or less to remove any slack in the apparatus.
j) Displacement measurement can also be read from the end of the bolt/ extensions to the floor directly below the axis of the bolt being pull tested using a potentiometer as shown in Figure 74, or an LVDT may be also be used as shown in Figure 75. Both LVDT and potentiometers will be ideal for measurements in laboratory tests.
k) Every bolt should be loaded until;
  i) past bond failure and up to a minimum 10mm displacement, or
  ii) up until the yield of the steel bolt is reached.

(3.2) Split Bolt SEPT

The spin and Stall installation procedure cannot be used to install normal SEPT test bolts, because of the length of bond is insufficient to induce nut breakout and drill stall as the nut is tightened, and the loads imposed on the bond are not therefore representative.

Split Bolt SEPT has been proposed, which consists of installing a two part decoupling rock bolt using a longer column
bonding. As shown in Figure 1, the decoupled bolt has two sections connected together by a stepped keyway. The keyway allows the bolt to be pushed into the hole and installed using the spin and stall installation procedure. When the bolt is subsequently pull tested, the section below the joint detaches freely, allowing measurements of the bond strength over this bolt section. Once the bolt is installed in the rock mass the procedure for SEPT is the same as above.

4) Calculations and Data Analysis

The method of graphing load versus bond displacement should be used, which calculates bond displacement as the raw displacement measurement minus the theoretical elongation of the free bolt length. Further work is required on the best method(s) which describe all features of the resin/bolt performance. Additional calculations shall include:

i. Peak Load: The maximum load at failure
ii. Residual Load: the minimum load after 25 mm of displacement
iii. Bond Strength: Taken as a gradient of the curve at 20 kN/mm
iv. Stiffness: Determined from the plotted graph

Figure 72- Split bolt short encapsulation pull testing
Figure 73- Dial gauge mounted on a Pogo Stick

Figure 74- Displacement reading with Potentiometer
Figure 75- An LVDT clamped to a magnet holder

Figure 76- An example of pulled-out bolts end encapsulation
9. CONCLUSIONS AND RECOMMENDATIONS

Field study and short encapsulation bolt pull testing study

The following conclusions were inferred from filed pull testing study:

- Bolt installation time of approximately 10 s constitutes an acceptable time for effective bolt installation as is normally recommended for use with Minova/Orica fast setting resin of 14 s,
- The results of the over spinning at back was inconclusive, because of the limited bolt encapsulation length,
- The use of 300 mm long encapsulation length may be the maximum acceptable length for pull testing. This may also depend on the type of the rock formation, which has some bearing on load transfer capability of the installation. This finding is in agreement with the study carried out by Wilkinson and Canbulat (2005).
- Over drilling contributed to increased load transfer capacity of the installed bolt and thus became the accumulation zone of the gloving material.
- Both Baal Bone and Tahmoor test analyses indicated that over drilling shows a significant improvement in load transfer.
- With regard to Gujarat NRE No.1 at Wongawilli formation installation it was inferred that all bolts installed in the 50 mm over-drilled holes (bolts 1-4) had relatively higher pull out loads than the ones installed without over drilling (5-8).
- As expected the bolt installed with anchorage length of 320 mm resulted in pull out loads greater than the pull out loads of 300 mm anchorage length. This additional length of 20 mm encapsulation length appears to cause pull out loads was near bolt yield point.

Bolt encapsulation pull testing in steel tube

No conclusions were drawn from the study of the encapsulated bolt in steel tubes because of poor pull loads. Further study is currently underway with new set of installations at the Springvale mine.

Laboratory overhead pull testing in sandstone

No conclusions were drawn at this stage from pull testing in overhead laboratory sandstone. Issues related to drill machine interfered with the study programme. The performance of the drill machine is currently been addressed for new programme of pull testing.

Resin strength properties testing

The new method of casting multiple resin samples in the same bunch represents a convenient method of preparing samples for strength testing. The prepared samples have been found to be of uniform composition and yielded consistent results. The proposed method of casting samples is:

- faster than the previous methods as no additional time is required for repeated casting;
- sample sides are uniform as moulds are not split axially;
- can be applied to cylinders as well as cube sample preparation;
- reduces the formation of voids and improves the quality of the cast sample.

Accordingly, the strength values determined for various resins are consistent and repeatable, thus the proposed methodology of resin casting represent a suitable approach which will permit setting up a useful testing procedure for the establishment of a credible Australian Standard.
Recommendations

It is recommended that further work to be carried out in order to bring this programme of study into successful conclusions and leading to the establishment of a viable Australian standard for bolt installations in mines. The said recommendations should include:

i) Assessment of optimum hole size for optimum load transfer capacity in both hard and soft rock
ii) Examination of the bolt installation spin time
iii) Further tests of bolt/tube encapsulation pull test,
iv) Continuation of the laboratory tests in overheard sandstone blocks to determine various installations spin time and other pertinent parameters such as drill motor rpm and applied thrust.

v) Preparation of procedures for underground SEPT
vi) Completion of resins and grouts properties evaluation, leading to the establishment of common procedures for testing of resins and grouts by manufacturers, consulting organisations, the Australian coal mining industry and beyond.

vii) It should be emphasised that the testing method utilised in this report is the recommended testing method for resin in the laboratory and underground, and has provided reliable and repeatable results for the establishment of an Australian standard, which is an ultimate objective of this study.

ACKNOWLEDGEMENTS

The research project has been funded by the Australian Coal Association Research Program (ACARP), project C21011. We are grateful for the cooperation of the personnel of Baal Bone, Tahmoor, Gujarat NRE No.1 and Springvale. Also many thanks to Jennmar Australia for providing bolts and assistance in the field trials, and Orica Australia in providing resins and expertise on resin usage and preparation of the cast samples.

The projectors mentors Brian Vorster of Glencore and Roger Byrnes of BHPBilliton- Illawarra Coal Holding for assisting the development and addressing various issues particularly during the first phase of the project execution period was appreciated.

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The authors accord Russell Howarth’s special role in maintaining a close scrutiny on the project and its progression, as the ACARP project monitor.

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REFERENCES


Jalalifar, H and Aziz N.I.,(2005). Load transfer in bending of bolt, Proc. 20th World Mining Congress and Exp, 7-10 Nov. Tehran, Iran, pp 285-293,


Figure 28- The alternative method of forcing mould bunch into the mixed resin container
Figure 29- Modified double layered mould for casting resin samples

Figure 31A- Green spots due to improper mixing of resin mastic and catalyst

Figure 31B- Two 40 mm diameter cast resin samples extruded from the latest modified mould. Note the consistency of the samples and without air bubbles as compared with poorly sample cast in A. as compared with poorly sample cast in A.
Figure 32A- UCS of the 4-day old samples

Figure 32B- A view of the angle of failure for a specimen after UCS test

Figure 33- Variation of Minova/Orica resin UCS properties with cure time

Figure 34- Variation of resin UCS changes with sample diameter
Figure 35 - Variation in resin UCS properties between 20 mm and 30 mm diameter resin sample size
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Figure A2- Wongawilli test site stratigraphic formation
Figure A3- Test site stratigraphic formation in the vicinity of Wongawilli seam
Figure A4- Wongawilli seam at NRE No.1 test site
**ROCK BOLTS**

**M24 TORQUE TENSION**

**Features**
- The "X" grade steel used by Jennmar has superior toughness and ductility through the use of grain refining alloys. The Jennmar "X" grade bolts should provide better performance in mines where Stress Corrosion Cracking is evident and also in areas of high localised horizontal stresses.
- The JX rock bolt profile provides superior load transfer characteristics using the unique "J" bar pattern.
- Recommended for drill hole sizes 27 – 28mm diameter
- M24 couplers, 30mm diameter are available for use with torque tension bolts
- Various roll pin break-out torque ranges available
- Available as galvanised

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Bar Straightness to AS 1442:1991

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<td>Cross sectional area (mm²)</td>
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Various torque rated shear pin break-out nuts available for use on M24 bolts

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Figure B- Specification of JXB Bolt
Lokset® Resin Capsules

For over 30 years Orica has lead the world in the development, manufacture and supply of resin capsules for rock bolting.

Lokset® resin capsules are used primarily as an anchoring medium for rock bolts and cable bolts to provide roof (backs) and sidewall support to underground excavations. Orica's Lokset® resin capsules are industry renowned for consistent quality and performance. With state of the art technical and manufacturing facilities, Orica provides an extensive and flexible range of resin capsules to suit all types of bolting parameters including variations in equipment, environment and strata conditions. Lokset® resin capsules consist of a reinforced non-hazardous polyester resin mastic in one compartment and organic peroxide catalyst separated by a physical barrier in the other compartment. The rotation of a rock bolt during installation ruptures the capsule, sheaths the skin and mixes the two components causing a chemical reaction and transforming the resin mastic into a solid anchor.

Over the past 30 years Orica has successfully introduced a range of revolutionary developments in resin capsules including the Lokset® TOOSPEEDIE® (1993), Lokset® X2 (1996), Lokset® Long Tendon (1998), Lokset® X2 (2000) and more recently the Lokset® Supamix® (2008) series. These developments have ensured that Australian mining and tunneling industries continue to lead the world in safe, efficient and consistent resin bolting.

Orica Australia resin capsule series are available in multiple configurations of length, double length combinations (X2), diameter, set time, set time combinations (TOOSPEEDIE®) and viscosity.

Advantages
Selection of the appropriate Lokset® capsule enables a wide variety of applications:

- Full encapsulation with pre-tensioning utilising combination TOOSPEEDIE® capsules
- Point anchor installation with fast set single speed Lokset® resin capsules
- Full encapsulation without pre-tensioning using slow set single speed Lokset® capsules
- Unique capsule configuration design enabling extremely effective mixing of resin mastic and catalyst compartments
- Rapid insertion, easy and quick to use
- High compressive strength, strong, rapid & consistent anchorage
- High modulus
- Protects bolt from corrosion, can be used in wet or underwater conditions
- Unaffected by vibration
- No expansion stresses, can be used in weak strata

Lokset® X2
- double length (joined) capsules enable full encapsulation mechanism bolting, for use in conjunction with Orica’s Quickchem® resin capsule insertion system

Lokset® Supamix®
- low mastic to catalyst ratio for improved mixing consistency and extended shelf life

Quick-Chem™
- Resin capsule insertion system
### Product Information

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<th>Label Colour</th>
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<th>Approx. Hold Time (seconds)</th>
<th>Gel Time 25°C (seconds)</th>
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The hold time is the minimum time allowed after completion of the spin time before bolt tensioning is attempted. In many cases the hold time will be greater than that listed. The times listed are an indication only, they may vary with temperature, mining conditions, equipment, hole: bolt annulus, age and storage conditions of resin capsules. Each mine site should be evaluated to determine optimum installation parameters. The following graph shows the effect of temperature on gel times.
Quality
The superior quality of Lokset® resin capsules is assured through a four-part quality control program:
1. Raw Material Testing
2. In-process quality control testing
3. Finished product acceptance testing
4. Quality system management to ISO 9001
Testing levels and specifications for each of the above programs have been established statistically, based on actual historical data to ensure the customer receives a uniform quality product which will perform dependably under field conditions.

Product Testing Specifications
A combination of testing is completed to ensure the ongoing quality control of Orca’s Lokset® resin capsule range. Each of the following tests forms an important part of this process.

Push out test
Measures to determine bond strength using a 22 mm bolt, 50 mm encapsulation in 28 mm I.D. threaded cylinder, with slow set Lokset® resin.

Pull out test
This is a routine test commonly performed on in-situ bolts to confirm effective anchorage. It is important to note that only short encapsulation in-situ tests can provide meaningful results. Orca’s QC tests are measured with fast set resin, 300 mm encapsulation in 80 MPa grout using 21.7 mm core diameter high tensile grade bolts in 28 mm diameter hole.

Punched Shear
Measured according to BS 7782 (part 3). The appropriate quantities of resin mastic and catalyst are mixed together for six (6) seconds. The resultant mixture squashed between two uniform flat steel plates and allowed to gel. The plates are taken apart and the cured slice of resin is placed between two steel templates. The device is placed in a tensiometer and a plunger is forced into a hole in the plates at a predetermined rate thus pushing a flat circular disc out of the resin slice (ie shearing the resin). The force applied to shear the resin is recorded electronically by the tensiometer and converted to shear stress in MPa using the thickness of the disc in mm.

This test provides excellent correlation with mine pull out tests (without the variances) and is directly related to the strength of the resin. With fast setting resins the test can be performed in a very short time after the resin mixture has gelled (15 seconds).
Application instructions

It is essential that good bolting procedures are followed and the instructions on the box are observed. As a guide the following steps must be taken:

1. Drill hole to correct diameter ensuring waterair flush is used. The hole should be clean and free from dust and other loose particles. In Coal mining 27–28 mm hole diameters are normally preferred with 22 mm core diameter roof bolts. Do not exceed the manufacturer’s recommended diameter.

2. Drill hole to correct length for bolt. The ideal hole length should be 100 mm – 140 mm shorter than the bolt, depending on attachments such as dome ball washer nut, plate etc. Do not deviate from the manufacturer’s recommended length of hole in relation to the bolt.

3. Select the correct resin capsule that has been specified for the job.

4. Check that the use by date on the box label has not expired.

5. Where FAST (or MEDIUM) and SLOW set capsules are used together, when pre-tensioning, it is essential that the FAST (or MEDIUM) set yellow or red capsule be inserted first followed by SLOW set (green) capsule. Push the capsule(s) until the first capsule touches the tip of the hole using the bolt or other insertion device if available.

Ensure the capsule reaches the top of the hole.

6. Should insertion problems occur then the problem must be investigated.

7. Connect the bolt to the spinning dolly/sparrow.

8. The bolt is pushed AND spun at maximum rpm at a constant feed rate through the entire length of the capsule, when the top of the hole is reached a further 2 – 4 seconds spinning will suffice to ensure complete mixing. Total spin time through the capsule and at the top of the hole should not exceed the “approximate spin time” on the box label. It is essential the bolt is pushed AND spun to the top of the hole before mixing is completed.

9. The bolt is then held stationary and after the hold time has elapsed the bolt may be tensioned as required. The hold time is the minimum time allowed after completion of the spin time before bolt tensioning can be attempted. In many cases the hold time will be greater than that listed.

10. The following items must also be checked where hand held (air operated) equipment is utilised.

- Compressed air supply should be clean and dry
- Air supply from roof bolter to miner should not be more than 100 metres of 2” hose
- Air pressure must be between 85–100 psi (586–690 KPa) when bolt(s) are operating
- Water pressure should be between 80–100 psi (550–620 KPa) and hoses flushed out prior to connection.

Limitations

The annular gap between bolt and hole diameter should be at a minimum. It is recommended the annular gap be between 4 – 6 mm e.g.:

- Bolt core diameter: 22 mm
- Hole diameter: 27 mm
- Annular gap: 5 mm

Where annular gaps larger than this are encountered (e.g. in metal mines) then the bolt must possess larger deformations or a mixing device such as Secure Bolts etc. and the installation guidelines followed. Larger hole diameters/Annular gaps can result in extended cure times, less efficient mixing, finger gloving of the bolt into the resin capsule, a reduction in load transfer (strength) and encapsulation length.

In all cases it is strongly recommended that short encapsulation pull tests be performed to verify that required load strengths are being achieved.

Extended tensioning times may be due to:

- Low temperatures
- Broken ground, large hole diameters
- Insufficient mixing
- High nut break out loads
- High machine torque load levels
- Excessive thrust/feel on the installation rig
- Over mixing of the resin well above the appropriate spin time

- Attempting to tension the bolt too soon and damaging the resin as it cures

The resin appearing to be “too quick” with the bolt not reaching the top of the hole may be due to:

- High temperatures
- Smaller hole diameters
- Hole closure
- Angled holes
- Misaligned holes/risks
- Low feed pressure
- Premature nut break out
- Old/dust of date resin

All bolting parameters will vary depending on a number of factors such as:

- Strata condition
- Type
- Holes, bolt annulus
- Age of resin capsule
- Equipment
- Installation method

Packaging

Lokset® Resin Capsules are available in standard diameters of 20 mm, nominal 25 mm (actual 23.6 mm), 26 mm, 30 mm, 36 mm and 38 mm. Lengths range from 300 mm to 1700 mm, with 20 providing additional length. They are packaged in water resistant cardboard cartons labeled with colour codes and supplied on wooden pallets.

Volume

It is essential the correct length of capsule is selected to fill the volume left in the hole after allowing for the volume of the bolt.

It is good practice to use a capsule size which exceeds this volume by around 10% to allow for variations in hole diameter and length, bolt size and strata conditions. Refer to encapsulation chart available at www.orica.com.au

82
Storage

Shelf Life

The Lokset® resin capsule suggested shelf life is 4 months when stored between 20–25°C. Storage at lower temperatures such as in cool rooms is highly recommended and will extend the shelf life when stored at 0–5°C. Stock rotation is strongly recommended. Storage at higher temperatures will reduce shelf life.

Storage Conditions

Lokset® resin capsules should be stored in a cool dry place away from direct sunlight. When using cool room storage the resin capsules should be allowed time to attain ambient temperature before use otherwise SPI N and HOLD TIMES will be extended.

Health and Safety

- Wear suitable protective clothing, gloves and eye/face protection
- In case of contact with skin remove contaminated clothing and immediately wash with soap and water, seek medical attention if skin irritation persists. In case of contact with eyes, flush with copious amounts of water and seek medical assistance
- If ingested remove from exposure and seek medical advice if effects persist
- If ingested wash out mouth with water and obtain medical attention
- For further information see the relevant material safety data sheet

Lokset® resin capsules are a single speed polyester resin mastic and organic peroxide catalyst system used for standard point anchor or fully encapsulated bolting requirements. Available in multiple lengths, diameters and set times, Lokset® resin capsules have been the benchmark for quality and performance in resin bolting for over 30 years.

Resin capsule product code breakdown:

<table>
<thead>
<tr>
<th>Typical code</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>RA65025F(C)</td>
<td>RA Lokset® resin anchoring capsule</td>
</tr>
<tr>
<td>650</td>
<td>Capsule length (650 mm)</td>
</tr>
<tr>
<td>25</td>
<td>Nominal capsule diameter (25 mm)</td>
</tr>
<tr>
<td>F</td>
<td>Set time (Fast)</td>
</tr>
<tr>
<td>C</td>
<td>A range of inclusions or attachments are also available such as cardboard cylinders (C), and are indicated by an additional letter at the end of the typical code.</td>
</tr>
</tbody>
</table>

Punch Shear Test

Measured according to BS 2782 (Part 3), with slow set Lokset® resin. Typical results:

<table>
<thead>
<tr>
<th>Age (hours)</th>
<th>Shear strength (MPa)</th>
</tr>
</thead>
<tbody>
<tr>
<td>24</td>
<td>&gt; 32</td>
</tr>
</tbody>
</table>

Push Out Test

Measured on 22 mm bolt, 50 mm encapsulation in 28 mm I.D. threaded cylinder, with slow set resin. Typical results:

<table>
<thead>
<tr>
<th>Age (hours)</th>
<th>Push out force (kN)</th>
</tr>
</thead>
<tbody>
<tr>
<td>24</td>
<td>&gt; 72</td>
</tr>
</tbody>
</table>

Pull Out Test

Measured with fast set Lokset® resin. 300 mm encapsulation in 60 MPa grout using 21.7 mm core diameter high tensile grade bolts in 28 mm diameter hole. Typical results:

<table>
<thead>
<tr>
<th>Age (hours)</th>
<th>Load (kN)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>&gt; 16</td>
</tr>
</tbody>
</table>
Figure 32: Pull test peak load values of different bolts installed in sand stone