INNOVATIVE ROCK REINFORCEMENT HARDWARE

By

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ABSTRACT

Two innovative ground reinforcement products have been developed for use in the mining industry. One of these products is a high strength polyethylene (HOPE) bar for use as a rib bolt in underground coal mining and as a corrosion proof tendon in open pit mines. The other product is a cable bolt (Ultrastrand) which demonstrates enhanced load transfer and is available in continuous lengths. Ultrastrand's exceptional initial performance and versatility makes it ideal for mechanised installation in both underground and surface mining operations. Details of these products are presented and results from laboratory and field trials are discussed.

INTRODUCTION

The mining industry continually seeks new technologies to improve its operations - ground support products are no exception to this rule. The demand for higher development and mining rates, safety issues and mining under difficult conditions all demand specialist high performance ground control products.

Roof bolts were first introduced into Australian coal mines in about 1948 when a very basic slot and wedge bolt was used at Elrington Colliery near Cessnock. In the 1960's the expansion bolt was developed and gained wide acceptance by the late 1960's early 1970's. Resin anchored bolts were first used about 20 years ago and gained general acceptance about 15 years ago. Dywidag bar was used at Cobar mine in about 1974. AX (high strength) bolts were developed first about 4 years ago and are now widely accepted in the underground coal mining industry. Split set bolts were introduced in about 1977. Cable bolts were first used in Broken Hill in about 1970, birdcage cable bolts were first used in about 1980 and the Garford bolt was first introduced in 1991.

The two developments described in this paper are regarded as niche products as their potential market is small compared to the total market size. They have been developed for specific market applications which are, in the main, technically driven.

HIGHLY ORIENTED POLYETHYLENE (HOPE) BAR

BACKGROUND

The BHP highly oriented polyethylene (HOPE) bar was developed for two specific mining applications - as a suitable rib bolt for underground coal mining and as a corrosion proof tendon for open pit mining applications. Existing rock reinforcement products for these two applications have proved to be unsatisfactory and there is a market need to reduce risks and uncertainties associated with the use of current products. It is appropriate to briefly review these two applications.

Underground Coal Operations

Retreat longwall coal mining usually requires the placement of reinforcing elements in the coal seam to control rib deformation and minimise spalling. Timber rib bolts have been used in the past with little success. In recent years, fibreglass rib bolts have been used with limited success. Fibreglass bolts have problems with load transfer, exceptionally high stiffness and installation.

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Steel rib bolts provide adequate support and have been used on a limited basis in some coal mines, however, because rib bolts are mined with the coal, operators are cognizant of the following potential problems.

- Conveyor belt damage.
- Cutter head (shearer) damage.
- Materials handling system blockages (at the mine and the coal washer).
- Ignition of methane due to pick-bolt impact.

Open pit mining operations

In many metalliferous mines, mine water is often acidic because of the presence of sulphides within the orebody. Steel tendons in these aggressive conditions corrode rapidly and lose their ability to function. An ensuing ground failure could cause temporary or permanent sterilization of the ore in the affected area.

LABORATORY TESTING

General

Research and preliminary testing was conducted at BHP's Research Laboratory in Melbourne. This was done in close collaboration with operating, consulting and other research bodies within the mining industry. Further product development, engineering implementation and commercialisation has been undertaken by BHP Engineering, with the co-operation of several mining operations.

The bar has been thoroughly tested in the laboratory and at numerous mine sites using the services of independent consultants including the CSIRO Geomechanics Division in Perth and Strait Control Technology Pty Ltd in Wollongong. Further testing on some particular aspects of the bars characteristics is planned for the near future.

Laboratory testing methods

A useful laboratory simulation of grouted rock reinforcement performance is the double embedment length test. The specimen can be loaded axially or in shear. The axial test arrangement is shown schematically in Fig 1. The rock is simulated by thick wall steel tubes which are used to contain the grout and reinforcing element. The interface between the two steel tubes represents a rock mass discontinuity. A zero gap (closed joint) was used in the experimental tests detailed below.

![Figure 1. Schematic diagram of the double embedment length laboratory pull test.](image)

Results of laboratory tests

1. Critical embedment

The full load capacity of the bar was developed when the embedment length was greater than 210 mm.

2. Shear test

The shear capacity of the 19 mm bolt is 57 kN (further test work is underway to verify and expand on this information).

3. Short duration axial tension tests

The summary of the results for the short duration tests with three different embedment lengths is given in Table 1. A typical load-displacement curve is shown in Fig 2.

Typical system stiffness is around 4 kN/mm as indicated in Fig 2.
Table 1 Summary of Short Duration Tension Tests

<table>
<thead>
<tr>
<th>Embedment Length (mm)</th>
<th>Failure Mode</th>
<th>Maximum Load (kN)</th>
<th>Nominal Stress (MPa)</th>
</tr>
</thead>
<tbody>
<tr>
<td>200</td>
<td>S</td>
<td>96</td>
<td>338</td>
</tr>
<tr>
<td></td>
<td>S</td>
<td>96</td>
<td>338</td>
</tr>
<tr>
<td>500</td>
<td>R</td>
<td>98</td>
<td>346</td>
</tr>
<tr>
<td></td>
<td>R</td>
<td>98</td>
<td>349</td>
</tr>
<tr>
<td>800</td>
<td>R</td>
<td>93</td>
<td>328</td>
</tr>
<tr>
<td></td>
<td>R</td>
<td>93</td>
<td>328</td>
</tr>
</tbody>
</table>

Notes
S = threads stripped from core
R = rupture of core

Figure 2 Short duration load-displacement response for 200 mm resin embedment.
4. Cyclic loading tests

A typical graph from the cyclic load tests on the HOPF bolt is presented in Figure 3. Specimens were loaded to failure following the cycles of loading. The peak load for the HOPF bolt was marginally lower than the peak loads recorded in the short duration tests.

5. Creep tests

A summary of the creep tests is given in Table 2. The four parameters of importance are the load level, rate of creep, displacement and the time to rupture where this form of failure occurred. Rupture occurred in all tests except the one with a nominal constant load of 25 kN.

The bar can tolerate high displacement (when compared to fibreglass bolts) prior to failure as indicated in Table 2. Further test work is being undertaken to provide further details on the long term behaviour of this material.

The results of creep tests are of concern, however, it should be noted that the test adopted was the most severe possible and the relevance of this type of test to all forms of fully ground rock and soil reinforcement needs further critical examination.

The creep test described above represents a 'worst case' load situation as could be expected in highly stressed, strong, blocky rock. The most important finding from this test is that the amount of deformation required to cause rupture of the HOPF bar. For the two cases where rupture occurred the total displacement was 75 mm and 38 mm for a constant load of 65 kN and 45 kN respectively. These are extremely high dilatations for a single discontinuity and would not normally be expected to occur in the access openings of most underground mines.

The creep test also highlighted the inability of HOPF to accept moderate load for a sustained period. HOPF is therefore inappropriate for applications where dead weight loads are experienced.

FIELD TESTING

Rib bolting in underground longwall coal mines

The bolt has been field trialled at Tower, Appin, Angus Place and Cordeaux Collieries in NSW. In-situ monitoring, at Tower and Angus Place Collieries was undertaken by Strata Control Technology Pty Ltd. The objective of the Angus Place trial was to compare the in-situ performance of all currently available non-steel rib bolts. The results of this trial are indicative of the results of trials at Tower and Appin Collieries. They can be summarised thus:

1. Generally speaking, there is no significant difference in loads generated by various dowel types. It should be noted however, that it is very difficult to measure loads in HOPF bolts because of the difficulties in cementing strain gauges to the bar's surface.

2. The visual appearance of the ribs reinforced with HOPF bolts, as well as the conditions of the bolts, was noticeably better than the other dowel types.

3. The improved end fixing system and the continuous thread of the HOPF bolt has assisted in maintaining the integrity of the skin of the ribs.

4. Despite the fact that potential creep effects in the HOPF material may tend to lower the long-term effectiveness of the bolt, the improved skin protection of the rib provided by the HOPF bolt provides benefits in all rib conditions.

5. The reduction in total rib deformation measured at the HOPF test site is a reflection of the improved skin provided by this bolt.

In summary, HOPF's in-situ performance is generally better than other non-steel rib bolts. Other benefits that may increase the marketability of the bolt are simplicity of installation, ease and safe handling and the fact that the long term projected price is much less than fibreglass bolts (and probably on a par with steel rib bolts). The high stress intensity, short duration nature of this application matches HOPF's current performance characteristics quite well.

Boiling in corrosive environments in open pit mines

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The bolt has been trialled at BHP Iron Ore’s Mt Newman mine. The mine has an acute groundwater problem where the pH can be as low as 3.5. Steel cable bolts have been known to corrode completely within 3 months of installation.

The HOPE bolt is being trialled in a very low load environment as a mesh pinning bolt. The purpose of this bolt is to assist in maintaining the integrity of slopes by preventing the skin from spalling and ravelling. It is not intended to prevent any deep seated failure.

**Embankment support**

The bolt is being trialled by the Roads and Traffic Authority of NSW as a soil nail. Preliminary results are favourable and further data will be made available in the near future.
ULTRASTRAND

BACKGROUND

Cable bolts have been used in various configurations in underground metalliferous mines since the 1970's. More recently they have been introduced in surface and underground coal mines. During this period the cable bolt and the manner in which it is applied have been under continual development.

The first major use of cable bolts was as a pre-reinforcement member in Cut-and-Fill Stoping. Great success was achieved in this application but success was not repeated when the same technology was applied to Long Hole Open Stoping to reinforce structural pillars and/or prevent dilution. Frequently, rock slipped off the cable bolt or the bolt was pulled out of the grout without rupturing. Clearly, the cause of the problem was insufficient load transfer between the cable bolt and surrounding cement grout.

To address this problem, barrel and wedge fittings were manually placed on the cable bolt at set intervals. A great improvement in performance was achieved but costs were excessive and quality control was difficult. The latter was overcome by swaging steel ferrules onto the cable bolt but this technique was costly.

The excessive cost of the swaging was a catalyst in the development of Birdcage Strand in the early 1980's at Broken Hill. This strand configuration is gradually finding acceptance in most applications but it does have the following limitations.

i) Cannot be manufactured in continuous lengths.

ii) Mechanised installation is difficult.

iii) Requires a relatively large hole and therefore drilling and grouting costs are not optimised.

iv) Cannot accommodate a barrel and wedge in the birdcage section and this is desirable for pre-reinforcement members used in cut-and-fill stoping.

ULTRASTRAND - GENERAL FEATURES AND APPLICATIONS

Ultrastrand has been designed in a manner to produce a cable bolt which has a superior performance to Standard Strand but available in a continuous length. This has been achieved by fixing a steel spacer at regular intervals to the king wire to form an enlarged cross section. The advantages of a strand modified in this manner are as follows.

i) Tensile forces in the cable bolt are transferred to the grout at the locations where the strand cross section is increased by spacers. This load transfer mechanism is far superior to friction and shear mechanisms associated with Birdcage and Standard Strand respectively.

ii) The compressive load transfer mechanism enables load transfer to continue at a high level of efficiency in grout which has suffered degradation by mechanical or chemical processes.

iii) Ultrastrand can be supplied as a continuous length on a spool which makes it ideal for mechanical installation. Other advantages of spooled supply include the following.

- increased flexibility at design and installation phases.

- Handling, transport and storage is simplified which also reduces the potential for damage and mistreatment prior to use. Strand in spooled form is also much safer and much more efficiently handled.

iv) The required drill hole diameter is much less than that required for other devices. Ultrastrand therefore generates large savings in drilling and grouting costs.

v) Load response stiffness of Ultrastrand can be matched to the application. Where a very stiff reinforcement is required, Ultrastrand with closely spaced nodes should be used. Where a much
softer performance is required, a strand with nodes at a greater spacing is recommended and a further softening effect is produced by decoupling the plain strand between load transfer nodes.

vi) It is considered that Ultradstrand can be fitted with a corrosion protective sheath without causing a reduction in its capacity to accept load. This is possible due to its positive load transfer mechanism. Ultradstrand in this form can be confidently used in most aggressive environments without the need to use expensive corrosion protection techniques used in civil engineering.

viii) Ultradstrand in its current configuration and material constituents is primarily an element for secondary reinforcement. It is considered that the same load transfer principle can be used to construct a flexible member for use in a primary reinforcement system.

Strand: 2 metre total length with a spacer located 0.5 m from both ends. Full encapsulation was used.

Details of the different strand configurations tested

i) Standard strand

Strand used in all tests was the super grade type as described in Australian Standard AS1311-1972. This strand has a uniform 15.2 mm diameter and the wavelength of each outer component wire is approximately 190 mm.

ii) Ultradstrand configurations

Two spacer sizes were evaluated, the small type had a wall thickness of 2.5 mm and the larger type was 5.0 mm causing the cross section of the 15.2 mm diameter strand to be increased to 20.2 mm and 25.2 mm respectively.

Tests were also performed on debonded (painted) samples to examine the effect of a reduction in friction between strand and grout. The majority of load transfer is then due to the mechanical interaction between the enlarged section of strand (caused by the spacer) and the cement grout.

iii) Birdcage configuration

The term "Birdcage Strand" is used to describe a strand with a repeated pattern of nodes and antinodes which in the sample tested was continuous over the entire length. The distance between adjacent nodes is 190 mm. The diameter of this sample ranged from 15.2 mm at the nodes to approximately 36 mm at the anti-nodes.

TEST RESULTS

Tables 3 and 4 summarise the test results for the different systems. The recorded values for Standard and Birdcage Strand are representative of at least two tests in each case.

INTERPRETATION OF RESULTS

The test program identified a number of important performance characteristics both within the Ultradstrand group and on a comparative basis with Standard and Birdcage Strands.

Data generated by the tests on strands with natural surface conditions provide a good basis for a direct
TABLE 3 Summary of Performance for Natural Surface Condition Strands

<table>
<thead>
<tr>
<th>Strand System</th>
<th>Grout Age (Days)</th>
<th>Embedment Length (Metres)</th>
<th>Yield Load (kN) Disp (mm)</th>
<th>Ultimate Load (kN) Disp (mm)</th>
<th>Failure Mode</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>8</td>
<td>1.0</td>
<td>200 66</td>
<td>250 40</td>
<td>R</td>
</tr>
<tr>
<td>1</td>
<td>28</td>
<td>1.0</td>
<td>200 58</td>
<td>250 32</td>
<td>R</td>
</tr>
<tr>
<td>2</td>
<td>8</td>
<td>1.0</td>
<td>200 72</td>
<td>245 26</td>
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<td>250 40</td>
<td>R</td>
</tr>
<tr>
<td>4</td>
<td>7</td>
<td>1.0</td>
<td>200 58</td>
<td>250 14</td>
<td>R</td>
</tr>
</tbody>
</table>

TABLE 4 Summary of Performance for Debonded (Painted) Surface Condition Strands

<table>
<thead>
<tr>
<th>Strand System</th>
<th>Grout Age (Days)</th>
<th>Embedment Length (Metres)</th>
<th>Yield Load (kN) Disp (mm)</th>
<th>Ultimate Load (kN) Disp (mm)</th>
<th>Failure Mode</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>8</td>
<td>1.0</td>
<td>185 140</td>
<td>160 &gt;185</td>
<td>S</td>
</tr>
<tr>
<td>2</td>
<td>8</td>
<td>1.0</td>
<td>200 56</td>
<td>250 120</td>
<td>R</td>
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<td>3</td>
<td>8</td>
<td>2.0</td>
<td>50 50</td>
<td>50 &gt;100</td>
<td>S</td>
</tr>
<tr>
<td>4</td>
<td>28</td>
<td>2.0</td>
<td>200 10</td>
<td>220 60</td>
<td>R</td>
</tr>
</tbody>
</table>

Notes for Tables 3 and 4:

1. BHP Ultrastrand (small ferrule) R = rupture of one or more component wires
2. BHP Ultrastrand (large ferrule) S = gross slip of strand
3. Standard Strand
4. Hindcage Strand

Strand System Failure Modes

comparison between the different strand configurations. It should be noted that Standard Strand with only 1 metre embedment can be pulled out of the grout without rupturing.

The tests on debonded configurations was undertaken for two reasons as follows.

i) To determine the absolute and relative performance of the Ultrastrand configurations in a debonded condition.

ii) To evaluate the effect on performance of a reduction in friction between strand and grout as could be expected from either a surface coating, placed deliberately or unintentionally, on the strand or poor quality grout.

The latter can be caused by poor workmanship at installation or more commonly as a result of sustained chemical attack by leachates.

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Performance with natural surface conditions

All configurations, except Standard Strand, have equivalent performance at yield or 220 kN. For Standard Strand, displacement at 200 kN is 20 mm or approximately four times that for the other configurations. The load transfer characteristics of Ultrastrand and Birdcage Strands is therefore superior to Standard Strand. All configurations produced rupture of the strand at about the nominal ultimate tensile capacity of the strand. The load response curves are shown in diagramatic form in Fig. 4.

Performance with debonded surface condition

Ultrastrand with large spacers and Birdcage Strand were both able to generate the full load capacity of the strand. The load transfer of Birdcage Strand in this test was superior than that for Ultrastrand (large). However, it should be noted that the degree of decoupling for these configurations was markedly different. The Birdcage Strand had a light paint coating applied by spray can on the outer surface only of the wires, the inner surface was left in its natural condition. On the other hand, Ultrastrand had the same paint coating applied to the entire exposed surface. Ultrastrand therefore had its entire steel/grout interactive surface totally decoupled but the Birdcage Strand retained its primary or inner surface in the natural condition. Therefore, the test arrangement did not provide a means for comparing the two configurations in a quantitative manner. Further work is planned to test both configurations in a range of grout qualities.

The load response curves are shown in diagramatic form in Fig. 5.

CONCLUSIONS

POLYETHYLENE (HOPE) BAR

1. The market for the HOPE bar is envisaged to be in the area of either
   A. Low stress environments (eg mesh pinning), or
   B. high intensity, short duration stress environments (eg rib bolting),
   coupled with corrosion and/or cuttable requirements.

2. The bolt reduces uncertainties in rib bolting and mesh pinning support applications due to its superior performance when compared to existing rock reinforcement products.

3. Because the construction material has performance characteristics that are extremely different to steel each application must be carefully reviewed to ensure fitness for purpose.

4. The HOPE bolt provides a partial solution to problems in two specific applications and reduces the risks involved - it is not the panacea for ground stabilisation in difficult ground conditions. It is almost certain that continuing development will produce far superior products in the not too distant future.

ULTRAstrand CABLE BOLT

1. Ultrastrand with a 5 mm spacer has better performance than 2.5 mm spacer configuration. The results suggest that further testing is desirable on specimens with larger spacers to determine optimum size.

2. The load transfer mechanics for both sizes of Ultrastrand as tested are superior to Standard Strand.

3. It could be argued that the performance of Ultrastrand is also superior to Birdcage when both have natural surface condition. At yield or 200 kN, both configurations have equivalent stiffness but beyond this point Ultrastrand is able to tolerate much greater displacement without rupturing. This characteristic is desirable in many ground reinforcement applications, particularly the high stress underground environment.

4. The decoupled test program as reported does not provide the basis for a qualitative comparison of the different cable configurations. In particular, the embedment length of the Birdcage test specimens was twice that of the Ultrastrand specimens. In addition, the decoupling of the strand configurations was dissimilar. These fundamental differences in the test specimens have distorted the test results to an unsatisfactory degree. Further laboratory tests are being planned to eliminate these problems.
Figure 4: Axial Test Results for Standard, Birdcage and Ultrastrand Cables with debonded surface condition. (Note: Birdcage and Standard cable test specimens had embedment lengths of two metres, both Ultrastrand specimens had only one metre embedment).

Figure 5: Axial test results for Standard, Birdcage and Ultrastrand Cables with natural surface condition. (Note: all test specimens had one metre embedment except standard cable which had two metres of confinement).

REFERENCES


11th International Conference on Ground Control in Mining, The University of Wollongong, N.S.W., July 1992.