

# The Development, Testing and Application of a Non-Steel Tendon for Artificial Ground Support

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## 1. INTRODUCTION

### 1.1 Preamble

Ground support problems faced by mine operators are a function of the extraction technique used and geotechnical conditions associated with the mining method (surrounding rock type, stress fields etc) (Gale, 1991). It is probably true to say that the development of rock reinforcement hardware and associated equipment always lags behind the development and implementation of mining methods - this is to be expected.

The lag in the development of suitable rock reinforcement hardware can create adverse situations which may effect the profitability of the mining operations and can lead to hazardous working conditions. For example, highly capitalised underground coal mine operations cannot tolerate unscheduled stoppages of equipment caused directly by ground support problems. Similarly, a large surface mine with a lifespan of many years, is heavily reliant on the ground reinforcement system to continue to operate at its full design capacity for the duration of the mining activity.

Current mining techniques will continue to be used for many years and rock reinforcement hardware is being continually developed and improved to allow the extraction techniques to be exploited to their maximum potential.

The BHP highly oriented polyethylene (HOPE) bar was developed for two specific mining applications - as a cuttable 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.

### 1.2 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 in the areas of load transfer, exceptionally high stiffness and installation.

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 washery).
- Ignition of methane due to pick-bolt impact.

### 1.3 Open Pit Mining Operations

In many large metalliferous mines, corrosion of steel cable bolts is a problem. 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.

### 1.4 Risk Reduction

The HOPE bolt was specifically developed to reduce uncertainties associated with current rock reinforcement hardware in niche applications - ie risks of damage to equipment and personnel and the risk of ground failure due to failure of the support elements.

## 2. LABORATORY AND FIELD TESTING

### 2.1 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 Strata Control Technology Pty Ltd in Wollongong. Further testing on some particular aspects of the bar's characteristics is planned for the near future.

## 2.2 Composition and Geometry

The bar is made from die drawn high density polyethylene. The die drawing process aligns the internal molecular structure imparting greatly improved mechanical properties to the material.

The bar can be made in a range of sizes, however, current dimensions are: root diameter - 19 mm, outside diameter - 23 mm (these are the dimensions of the bar used in the tests reported in Sections 2.3, 2.4 and 3). Typical maximum production lengths are currently around 25 m.

The bar is threaded over its entire length - this feature ensures good load transfer between the bar and the surrounding grout.

The general properties of polyethylene are as follows.

1. Chemical Resistance: Excellent for all acids and alkalis.
2. Weathering Resistance: Ultraviolet light in the presence of oxygen does degrade the mechanical properties. This can be overcome with appropriate packaging materials (for storage purposes) and the addition of carbon black for surface mining (out-door) applications.
3. Resistance to Attack by Animals and Micro-organisms: Polyethylene is not a nutrient medium and is not attacked by any plant or animal life form.
4. Water Absorption: Polyethylene is water repellent, does not swell when immersed in water and changes in humidity have no effect.
5. Melting Point and Service Temperature: Melting Point is 140°C and it is recommended that the bar is only used in temperatures below 50°C.
6. Flammability: Untreated bars, after ignition, burn with a faintly luminous flame. It continues to burn when the ignition source is removed with burning drips. Spontaneous ignition temperature is approx. 350°C and the temperature at which ignition is induced from an external source is 340°C. Combustion of

polyethylene bar produces no environmentally relevant pollutants.

7. Electrical Properties: Surface resistance is greater than  $10^{13}$  ohms. The bar is inclined to become electrostatically charged. This problem can be overcome by the addition of an antistatic agent at manufacture or applying a coating following fabrication.
8. Density: Slightly less than water (1.0) - around 1/8 that of steel.
9. Handling Aspects: Polyethylene emits no vapours and is safe to touch. These properties are reflected in the use of this material for food containers, water pipes, storage crates, etc. The bar does not splinter or fracture. Its light weight makes it extremely easy to man-handle and install.

## 2.3 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. This is considered to be the most severe test possible since the displacement is concentrated at one point on the bar.

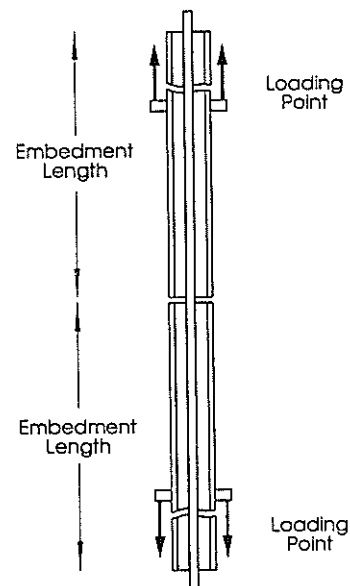


Figure 1 Schematic diagram of the double embedment length laboratory tension test.

Celtite Resifix 2 resin was used to anchor the HOPE bolts in the steel tubes. It is necessary with small diameter tubes to increase the load transfer between the grout and the steel tube by roughening the internal surface. This was achieved in this testing program by machining or tapping a coarse thread inside the steel tube.

A number of different types of loading are possible to provide data relevant to different applications. In this test program, short duration axial tension tests, shear, cyclic axial tension loading and long term axial tension constant loading tests were performed.

### 2.3.1 Short Duration Tests

The short duration axial tension and shear tests were designed to define the peak capacity of the HOPE bolt, the stiffness of response and the critical embedment length of the bolt in the grout. These parameters are required for comparison with other reinforcing devices and for design purposes.

It is not generally possible to directly extrapolate the results from short embedment length tests to longer lengths to define the minimum embedment length required to transfer the peak capacity of the reinforcing element. Extrapolation can be used only when the load transfer between the reinforcing element and the grout is uniform along the embedment length. Extrapolation is unreliable with a soft material (such as the HOPE bolt) which results in non-uniform load transfer between the reinforcing element and the grout and progressive shearing of the threads.

### 2.3.2 Cyclic Loading Tests

Mining operations produce changes in the stress regime where reinforcement has been installed. Operations over a period of time may cause cyclic loading of reinforcement. This may have a deleterious effect on the ultimate reinforcement capacity. The cyclic loading tests were designed to determine the ability of the HOPE bolt to recover strain. Elastic materials will show very little or any hysteresis to loading cycles below the elastic limit.

HOPE material is inherently both non-elastic and non-linear. Other materials with these characteristics sometimes exhibit a stabilised response as the number of cycles increases. That is, further damage to the material only occurs when the load is increased beyond the maximum level to which the materials has been subjected previously. The tests were also designed to determine whether progressive damage occurs during the extra cycles of load compared with a test loaded directly to failure. Any damage caused by cycles of load will be reflected by a reduction in the peak capacity.

### 2.3.3 Creep Tests

Polymeric materials are known to have high creep rates when compared with traditional engineering materials such as steel, aluminium and concrete. The

creep characteristics were identified as potentially the most important property which would govern the potential of HOPE material to replace existing reinforcing devices. It was originally intended to perform load relaxation monitoring as a means of evaluating the rate of creep of the HOPE material. Load relaxation tests require the establishment of a load in the reinforcement which is maintained by setting an anchor. Load variations with time are monitored using a load cell whilst maintaining the constant displaced position.

Due to the difficulties associated with anchoring HOPE material, creep tests were performed instead of the planned load relaxation tests. Creep tests involved monitoring the displacement of the specimen whilst maintaining a constant load.

## 2.4 RESULTS OF LABORATORY TESTS

### 2.4.1 Critical Embedment

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

### 2.4.2 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).

### 2.4.3 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 Figure 2.

Typical system stiffness is around 4 kN/mm as indicated in Figure 2.

### 2.4.4 Cyclic Loading Tests

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

### 2.4.5 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

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Table 1 Summary of Short Duration Tension Tests

Embedment Length (mm)	Failure Mode	Maximum Load (kN)	Nominal Stress (MPa)
200	S	96	338
	S	96	338
500	R	98	346
	R	98	349
800	R	93	328
	R	93	328

Notes

S = threads stripped from core

R = rupture of core

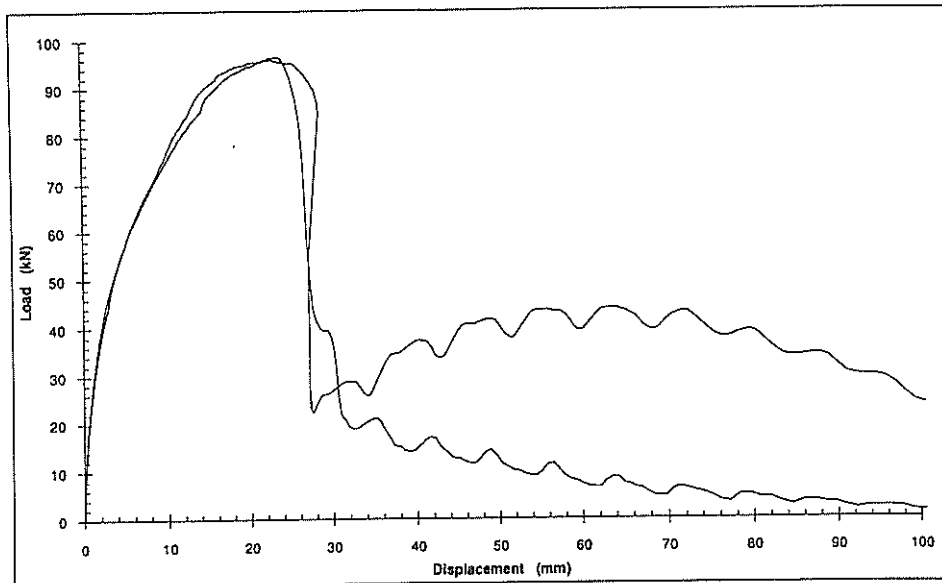


Figure 2 Short duration load-displacement response for 200 mm resin embedment.

Table 2 Summary of Creep Properties for HOPE Bolts

Nominal Load (kN)	Creep Rate (mm/hour)	Displacement (mm)	Failure Mode (hours)
65	0.83	75	R (18)
45	0.40	38	R (50)
25	0.03	16	N/A

Notes

R = rupture of HOPE bolt core

N/A = test discontinued before stability or rupture determined

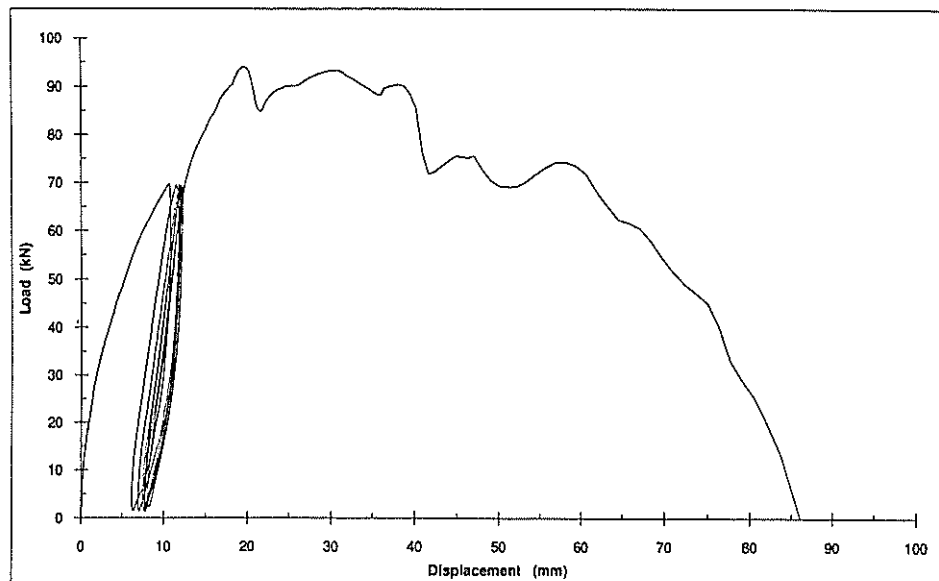


Figure 3 Cyclic load-displacement response curve.

all forms of fully grouted 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 the amount of deformation required to cause rupture of the HOPE 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 dilations 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 HOPE to accept moderate load for a sustained period. HOPE is therefore inappropriate for applications where dead weight loads are experienced.

### 3. FIELD TESTING

#### 3.1 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 HOPE bolts because of the difficulties in cementing strain gauges to the bar's surface.

2. The visual appearance of the ribs reinforced with HOPE 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 HOPE bolt has assisted in maintaining the integrity of the skin of the ribs.
4. Despite the fact that potential creep effects in the HOPE material may tend to lower the long-term effectiveness of the bolt, the improved skin protection of the rib provided by the HOPE bolt provides benefits in all rib conditions.
5. The reduction in total rib deformation measured at the HOPE test site is a reflection of the improved skin provided by this bolt.

In summary, HOPE'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, easy 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 HOPE's current performance characteristics quite well.

#### 3.2 Bolting in Corrosive Environments in Open Pit Mines

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 1.5. Steel cable bolts have been known to corrode completely within 3 months of installation.

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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.

### 3.3 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.

## 4. CONCLUSIONS

- 4.1 BHP has developed an innovative low cost, non-steel tendon for niche artificial ground support applications.
- 4.2 The market for the 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.

- 4.3 The bolt reduces uncertainties in rib bolting and mesh pinning support applications due to its superior performance when compared to existing rock reinforcement products.
- 4.4 Because the construction material has performance characteristics that are extremely different to steel each application must be carefully reviewed to ensure fitness for purpose.
- 4.5 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.

## 5. REFERENCES

Gale, W J (1991) Strata Control Utilising rock reinforcement Techniques and Stress Control methods, in Australian Coal Mines.

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