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A New Corosion Resistant Ground Support System

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ABSTRACT: The capacity of ground support components which have been affected by corrosion is reduced and may ultimately lead to failure of the component and the strata. In order to maintain an effective, long-term ground support system, significant campaigns of rehabilitation are often required in corrosion affected areas. The most common corrosion protection for steel ground support utilises sacrificial systems such as galvanising. Galvanising has previously been proven to be susceptible to some corrosion processes. Stainless steel is the most effective in resistance to corrosion, but can be cost prohibitive, and its mechanical properties often make it unsuited for use in ground support components.

Providing an outer protective plastic coating to bolts has proven to be an effective means of protecting the inner steel bar from corrosion. However, these support systems tend to be heavy, and require post point anchor cement grouting to provide full encapsulation. In comparison to a standard bolt/resin system, they are slow to install and expensive. These systems have also been shown to reduce overall load transfer performance of the bolting system.

In order to provide a higher level of corrosion protection whilst maintaining current installation practises and bolting cycle times, Minova has developed the Enduro™ steel ground support range. The Enduro™ range consists of standard Minova steel ground support components which have been treated with a unique coating process. The Enduro™ coating has been tested in the harshest of conditions, both underground and in controlled laboratory conditions. It has been proven to effectively resist or eliminate the formation of corrosion, even in the most aggressive environments. This paper outlines the laboratory and underground corrosion performance testing carried out on Enduro™ ground support products.

INTRODUCTION

Traditionally, the most common form of corrosion protection in steel ground support consists of a sacrificial protective coating such as galvanising. Such coatings have proven to be ineffective in extreme high and low pH conditions with corrosion of the support system commonly encountered. There is also evidence that common forms of galvanising may actually increase the rate of corrosion in certain pH environments. Figure 1 shows typical corrosion and failure on a standard re-bar roof bolt.

Figure 1: Corroded and failed roof bolt

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In order to provide additional protection, Double Corrosion Protected systems were introduced. These systems, although effective in providing additional corrosion protection, have proven to be expensive, complex to manufacture, bulky and difficult to handle. They are normally slow to install which leads to a reduction in development rates. In addition to these challenges, Clarke and Sieders (2014) identified that the plastic layer between the steel bolt and anchor may impact the axial load stiffness of the ground support.

Due to these limitations in the double corrosion protection systems, Minova developed the Enduro™ range of steel ground support products. The Enduro™ bolt, whether it be a solid bolt or friction bolt, is installed like any other common bolting system. It is no heavier than a standard bolt and requires no additional training or special equipment to be installed.

ENDURO COATING

There are two components to the Enduro™ coating:

1. The Enduro™ or base coat which covers the entire surface area of the bolt. The Enduro™ coating is a unique and protected Minova application to ground support components.
2. An optional top coat applied to either the entire surface area or selected sections (i.e. the exposed tail of bolt).

The Enduro™ coat is applied using the Cathodic Dip Coating (CDC) process. In this process the system applies a Direct Current (DC) charge to the component, which is immersed in a bath of oppositely charged coating particles. The particles are drawn to the component surface and are deposited forming an even, continuous film over the surface (including every crevice) until the coating reaches the desired thickness, typically 100 µm

An optional top coat is applied using a Thermoplastic Powder Coating (TPC)process and is suitable for most metals that can withstand 180°C oven temperatures that are required for curing the powder. The thickness of T P C is typically 150 µm -250 µm. The top coat can be used to provide extra confidence in the protection of the steel, particularly where physical damage through extreme handling may be encountered. It is also effective in UV protection to the Enduro™ coat should the tail be exposed.

The thickness of either the Enduro™ or top coat can be increased, or the coating process repeated to provide even greater confidence in the corrosion protection.

LABORATORY TESTING AND RESULTS

In order to validate the performance of the Enduro™ product, a series of controlled laboratory tests have been completed. A summary is provided below.

Corrosion Resistance Acetic Acid Salt Spray (AASS)

The corrosion resistance performance of the Enduro™ product in A ASS has been observed over 1000 hours and compared witha traditional galvanised bolt. A total of three bolts were tested that included a 'standard' galvanised bolt, a bolt with an Enduro™ base coat and a bolt with a Enduro™ base coat and a topcoat.

The salt spray chamber used to perform the tests is shown in Figure 2.

Test conditions were pH 3.1 – 3.3 @ +35^{o}C. The test results for each of the three coating types are provided in Table 1 and Figure 3.

Figure 2: Salt spray chamber used for Enduro™ product testing

Table1: Acetic Acid Salt Spray Results

AASS Testing Hours	257	518	722	1012
Description	Corrosion observations after elapsed hours			
Required Specifications	No visible corrosion observed for acceptable performance result			
Galvanised Bolt	Severe white rust, some red rust	Severe white rust, some red rust	Severe white & red rust	Severe white & red rust
Observed Result	Fail	Fail	Fail	Fail
Enduro™ Bolt (base coat only)	No visible corrosion	No visible corrosion	Minor red rust spots	Minor red rust spots
Observed Result	Pass	Pass	Fail	Fail
Enduro™ Bolt (base coat and topcoat)	No visible corrosion	No visible corrosion	No visible corrosion	No visible corrosion
Observed Result	Pass	Pass	Pass	Pass

Despite galvanised bolts being used extensively to protect against corrosion in saline conditions, laboratory testing conducted herein presents obvious signs of corrosion. Better corrosion resistance has been observed (when compared withthe galvanised bolt) by the two Enduro™ variant coated bolts. The product with both base and topcoat provided the best resistance to corrosion under saline conditions.

Acid bath immersion

The acid resistance of the Enduro™ product in a low acid environment has been observed and compared with a traditional bolt materials. A total of three bolts were tested that included a 'standard' hot-dip galvanised bolt, a bolt with an Enduro™ base coat and a bolt developed from raw steel.

A straight forward test procedure was used whereby each of the products were placed in an acidic solution (dilute sulphuric acid with a pH of 1.69) for a period of 50 days. The visual appearance was observed and recorded at 30 minute, 5 day, 21 day and 50 day increments for each of the bolt types.

The acid bath and pH measuring instrument is shown in Figure 4.

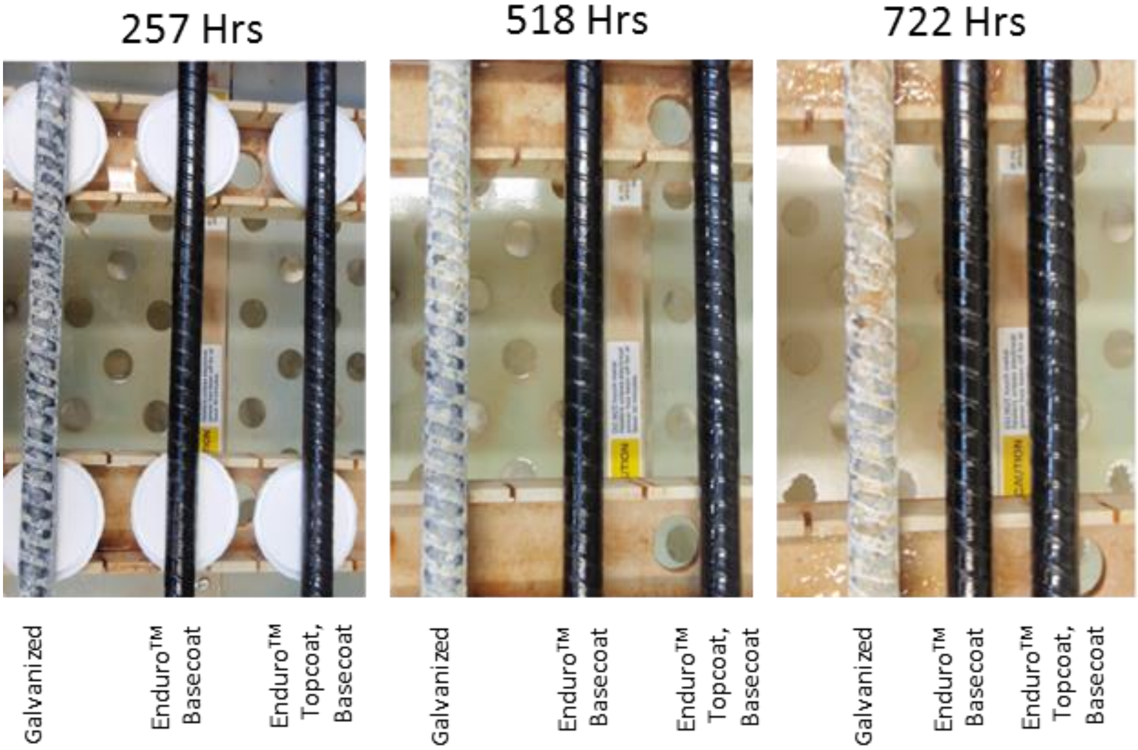

Figure 3: Corrosion observations during AASS testing at 257, 518 and 722 hours

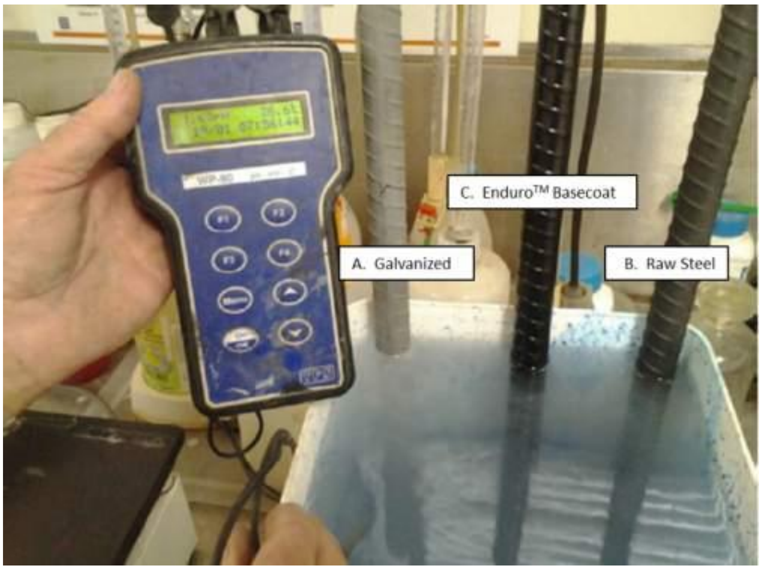

Figure 4: Acid bath and pH monitoring instrument used during Enduro™ product testing

Immediately upon immersion, the hot-dip galvanized bolt (grey colour – Figure 4a) commenced 'fizzing' (reacting). The raw steel bolt (charcoal colour- Figure 4b) commenced reacting after approximately 30 minutes. Over a period of testing there was no apparent reaction with the black Enduro™ base coated bolt (Figure 4c).

After 5 days of immersion, a pH of 2.25 was measured. Sheets of corroded material can be seen on the galvanized and raw steel bolt. There was no corrosion observed on the Enduro™ bolt (Figure 5 left). After 21 days, additional corrosion was observed on the raw steel and galvanised bolts (Figure 5 right).

Figure 5: Acid bath test results after 5 and 21 days

After 50 days (Figure 6) both the raw steel and galvanised bolts have corroded significantly with the nut on the galvanised bolt completely corroded. There were still no obvious signs of corrosion on the Enduro^{TM} bolt.

Figure 6: Acid bath immersion testing results after 50 days

From the observations it is clear that the galvanised and the raw steel bolt were severely corroded after 50 days of immersion. The Enduro™ bolt still loked 'intact' with no apparent corrosion evident. The dissolution pattern of the raw and galvanized bolts appears different;

- the raw bolt appears to be dissolving uniformly with the nut showing severe corrosion.
- the galvanized bolt shows severe pitting and complete dissolution of the nut.

In both cases, the threaded areas of the raw steel and galvanized bolt area has been significantly reduced in diameter. The Enduro™ nut and thread is observed to be unaffected showing no signs of corrosion (Figure 6).

Accelerated corrosion tests

Monash University has conducted accelerated corrosion tests to provide a rapid comparison of the corrosion resistance of the Enduro™ product to other products in the marketplace and determine corrosion expected from 2 years to 100 years (specifically thickness loss data in mm/y).
To complete the tests, a test solution of 3.5 wt% NaCl, was prepared by dissolving 35 g of NaCl in 1 L of distilled water. This solution has a normal pH of approximately 7.8. For the development of other pH solutions, 0.1 N solutions of HCl or NaOH were added to achieve pH environments of 2, 7 and 9 for

testing. The accelerated corrosion testing procedure used included taking potentiodynamic polarization measurements using a typical three-electrode electrochemical cell that was connected with a Bio-Logic potentiostat. Prior to each corrosion test the Open Circuit Potential (OCP) was measured to confirm stability over a period of 1000 seconds. A total of five bolt materials were tested that included; Enduro™ with base coat, black (e.g. ungalvanised), hot dip galvanisation, Thermally Diffused Galvanisation (TDG) and stainless steel. Results for each of the products at pH 2 are presented in Figure 7.

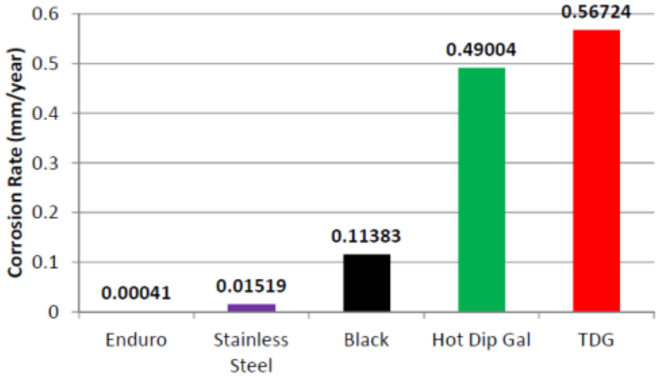

Figure 7: Average calculated corrosion rate of Enduro™ and comparison samples in 3.5% NaCl solution, pH 2

The Enduro™ product specimens provided the best observed corrosion resistance in acidic conditions (3.5% NaCl at pH 2) followed by stainless steel and then the other products tested. It can be observed that HDG and TDG coatings have extremely low resistance to corrosion from low pH solutions

The corrosion performance of the Enduro™ product (basecoat only) over a range of pH conditions is provided in Figure 8 for the purposes of estimating service life.

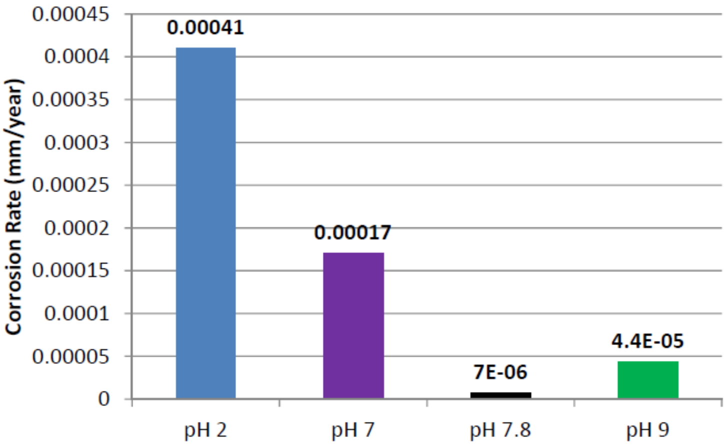

Figure 8: Enduro Corrosion (mm/yr) calculated at various pH levels

FIELD TESTING AND RESULTS

A series of underground tests on the Enduro™ product were carried out to determine the durability of the bolt when exposed to highly acidic mine water. A summary of the in situ trials are provided below.

Mine A

Six sections of Enduro™ bolts (Type A) and six sections of Hot Dip Galvanised bolts (Type B) were selected for use in this trial. Each section was 600 mm in length. The bolts were placed underground in free running/draining acidic water as shown in Figure 9. The pH was measured once a week and is also provided in Figure 9.

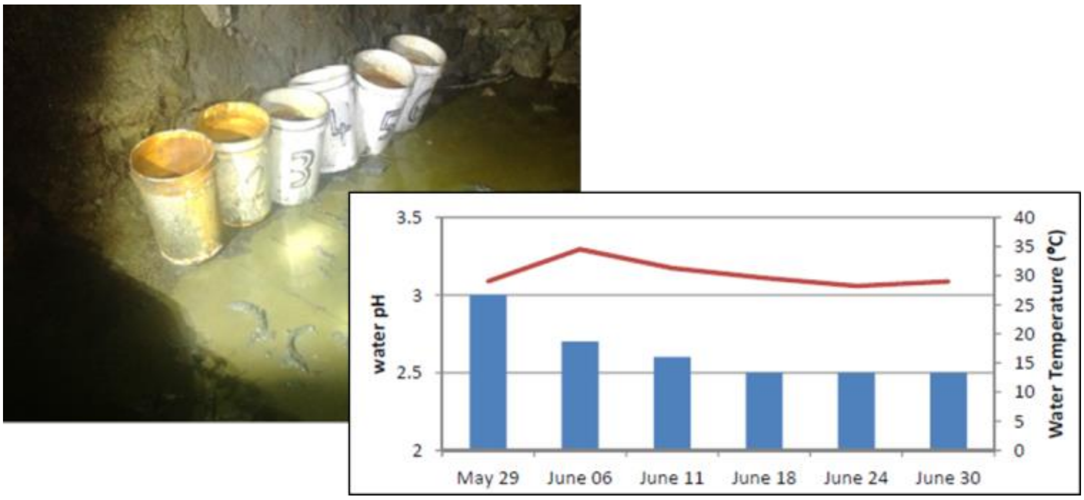

Figure 9: Mine A Bolt in situ test conditions

After 30 days, a section of each bolt type were removed from the acidic water and the excess build up was removed and the level of corrosion observed (Figure 10). It can be seen, that under the highly acidic mine water conditions at Mine A, the Enduro™ bolt outperforms the hot dip galvanised bolt in resisting the effects of the corrosive mine water.

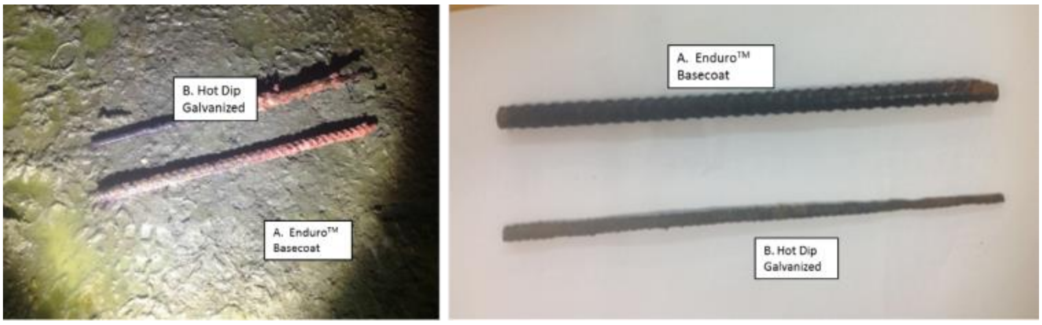

Figure 10: Mine A after 30 days (left) bolts observed underground (right) excess build up removed from bolts

Figure 11 presents a solid Enduro™ bolt that has been installed for six weeks at Mine A. At this point discoloration is observed but no corrosion is evident on the bolt. The galvanized mesh surrounding the Enduro™ bolt is eight weeks old.

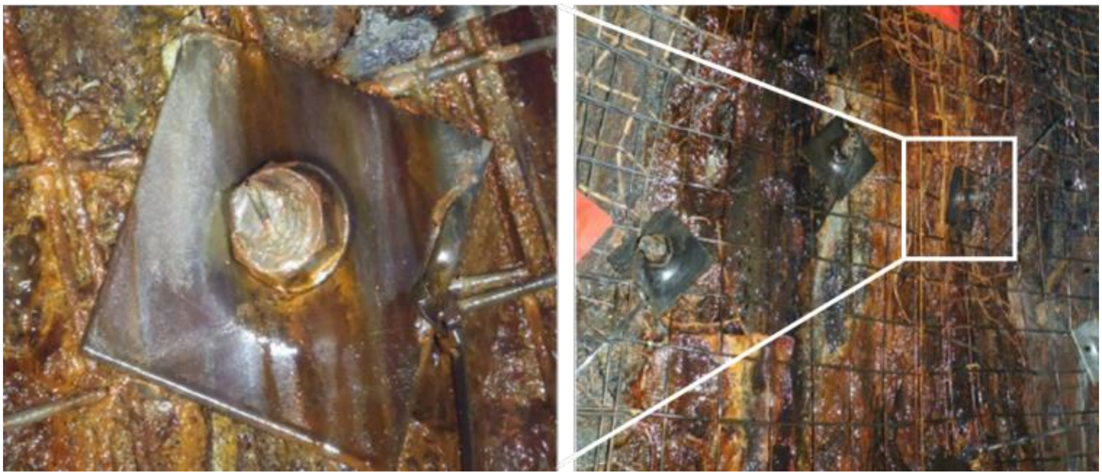

Figure 11: In situ observations of the performance of an Enduro™ bolt in comparison to galvanized mesh in acidic mine groundwater conditions

Mine B

At Mine B, *in situ* trial sites for the Enduro^{TM} product were selected based on a significant observed degradation in the existing galvanised split-set support which had been installed approximately three years previously and was re-supported. Figure 12a shows a heavily corroded split set and plate that has been installed for approximately two weeks. Visual observations regarding the corrosion of the bolts have been made in addition to corrosion assessments of the inside of the bolts using a hand-held wand camera (Figure 12b). The performance of the Enduro^{TM} product was measured (along with what is called red bolt) over a two month period whereby exposure of the bolts was maximised by placing them on the floor under dripping mine water (Figure 13). In order to replicate mining conditions the bolts were extensively scratched and scoured on the inside and outside. The extent of corrosion on the bolts was recorded every month. The red-bolt and the black Enduro™ bolt showed minimal evidence of corrosion over a two month period.

Figure 12: Observed corrosion of existing galvanized ground support through surface and penetrating visual means at Mine B

Figure 13: Observed corrosion of Enduro^{TM} (black) and (red-bolt) at Mine B

Underground installation at Mine C

Minova was approached regarding the support system currently being installed in Mine C's surface to underground declines. Mine C were having issues complying with the geotechnical design criteria to fully encapsulate the bolt prior to the application of shotcrete. At the time Minova got involved, this issue was severely hindering development rates and had led to a substantial amount of re-support having to be carried out.

Minova proposed using the Enduro™ solid bolt along with our standard resin anchor to overcome this issue. Having proved the durability of the Enduro™ bolt, the system was adopted. Mine C was able to accept a less than 100% encapsulation of the bolt due to its effective resistance to corrosion. Implementing this system also eliminated manual handling issues and exposure to cement dust encountered while using the previous post grouting system. As a result of the application of the Enduro^{TM} product, advance rates increased significantly and no further re-work was required.

CONCLUSIONS

Field and Laboratory testing of Enduro™ rockbolts and ground support components have shown significant reductions in rates of corrosion compared to other traditional corrosion resistant steel ground support systems. Additionally, Enduro™ bolt installation offers significant efficiency benefits over other rock bolts in projects designed for a life of 100 years. It is believed that project designers and Geotechnical Engineers now have a viable new ground support system to consider where long service life is required and / or extreme corrosion potential exists.

ACKNOWLEDGEMENTS

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