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Laboratory and field testing of bolting systems subjected to highly corrosive environments

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ABSTRACT

The capacity of ground support components which have been affected by corrosion is reduced and may ultimately lead to dynamic 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 which also expose the workers to hazardous conditions. 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 to 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 susceptible to coating damage, and require post cement grouting to provide full encapsulation. In comparison to a standard bolt/resin system, they can be 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 practices 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, in laboratory controlled conditions and in underground trials. It has been proven to effectively resist or completely eliminate the formation of corrosion, even in the most aggressive environments. This paper explains the process and provides the details of the laboratory and underground corrosion performance testing carried out on Enduro™ ground support products.

1. Introduction

Traditionally, the most common form of corrosion protection in steel ground support consists of a sacrificial protective coating such as galvanising [1]. Such coatings have proven to be ineffective in extreme high and low pH conditions with corrosion of the support system commonly encountered [2–4]. There is also evidence that common forms of galvanising may actually increase the rate of corrosion in certain pH environments. Fig. 1 shows typical corrosion and failure of a standard re-bar roof bolt.

In order to provide additional protection, double corrosion protected (DCP) 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. The outer layer can also be damaged during careless installations, permitting the coalescence of corrosive solutions on selected areas. Additionally flexible polymer coatings have been attempted in highly acid ground in two underground gold mines in Nevada, USA [5]. In addition to the challenges described above, Clarke and Sieders identified that the plastic "smooth" layer between the steel bolts may impact the axial load stiffness or friction of the installed ground support systems [6].

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.

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Fig. 1. Corroded and failed roof bolt.

It is no heavier than a standard bolt and requires no additional training or special equipment to be installed.

2. Endure coating

There are two components to the Enduro™ coating:

(1) The Enduro™ or base coat which covers 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. 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 20 μm.

An optional top coat is applied using a thermoplastic powder coating process and is suitable for most metals that can withstand 180 °C oven temperatures that are required for curing the powder. The thickness of thermoplastic powder coating is typically 150–250 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 after installation.

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 for extremely difficult environments.

3. Laboratory testing and results

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

3.1. Corrosion resistance acetic acid salt spray (AASS)

The corrosion resistance performance of the Enduro™ product in acetic acid salt spray (AASS) has been observed over 1000 h and compared to a 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 presented in Fig. 2.

Test conditions were pH 3.1–3.3@ + 35 °C. The test results for each of the three coating types are provided in Table 1.

Despite galvanised bolts being used extensively to protect against corrosion in saline conditions, laboratory testing conducted herein presents obvious signs of corrosion (see Fig. 3). Better corrosion resistance has been observed (when compared to the 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.

3.2. Acid bath immersion

The acid resistance of the Enduro™ product in a low acid environment has been observed and compared to 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 has been 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 min, 5, 21 and 50 day increments for each of the bolt types. The acid bath and pH measuring instrument is presented in Fig. 4.

Immediately upon immersion, the hot-dip galvanised bolt (grey colour Fig. 4, part A) commenced 'fizzing' (reacting). The raw steel bolt (charcoal colour Fig. 4, part B) commenced reacting after approximately 30 min. Over a period of testing, there was no apparent reaction with the black Enduro™ base coated bolt (Fig. 4, part C).

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

After 50 days (Fig. 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™ bolt.

From the observations, it is clear that the galvanised and the raw steel bolts are severely corroded after 50 days of immersion.

The Enduro™ bolt still looks 'intact' with no apparent corrosion evident. The dissolution pattern of the raw and galvanised bolt appears different: (1) the raw bolt appears to be dissolving uniformly with the nut showing severe corrosion, and (2) the galvanised bolt shows severe pitting and complete dissolution of the nut.

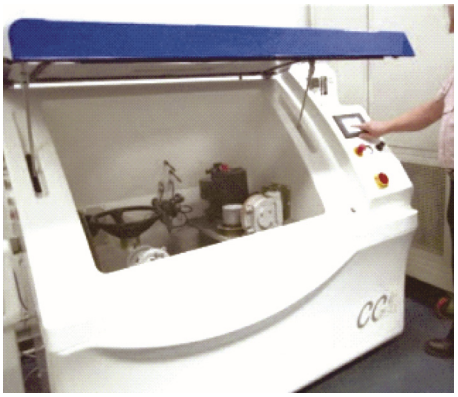

Fig. 2. Salt spray chamber used for Enduro™ product testing.