THE EFFECTS OF ENVIRONMENTAL FACTORS ON THE CORROSION RATE OF TGIC-FREE POLYESTER COATED MILD STEEL

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ABSTRACT

Nowadays, the applications of TGIC-free coated carbon steel in building industry is on the rise, mainly because it is less costly, effective in corrosion prevention and create least environmental hazards. However, the number of literatures focused on the technical evaluation of TGIC-free polyester coating as a corrosion protective layer is still very limited. The development in this green powder coating system mainly has focused on cost and health, environment and safety issues rather than new product development and product performance evaluation. The main purpose of this project is to investigate and compare the effects of solutions of different pH, seawater and tap water on the corrosion rates of TGIC-free polyester coated carbon steel and uncoated carbon steel of the same composition and dimension. The effects of these parameters on tensile strength and the significant or limitation of TGIC-free polyester coating also been investigated. The corrosion rate was determined by using weight loss method after a series of immersion tests and all these tests are done in accordance to ASTM G31. After the immersion test, both the coated and uncoated specimens were subjected to tensile test in accordance to ASTM E-8M. The laboratory result shows that this green coating system is effective in reducing the corrosion rates and increasing the tensile strengths of carbon steel under exposure to solutions of pH ranges from 3 to 12, tap water, and seawater. Also, TGIC-Free Polyester Coating shows particularly high durability in acidic solutions (solutions of pH 4 and below) and tap water.

ABSTRAK

Sejak kebelakangan ini, applikasi keluli yang dilapiskan dengan lapisan poliester bebas TGIC dalam industri pembinaan semakin meningkat disebabkan kos pelapisan yang rendah, keberkesanan dalam menangani pengaratan, dan membawa minimum implikasi negative terhadap alam sekeliling. Namun, jumlah literatur difokuskan pada penilaian teknikal lapisan poliester TGIC-bebas sebagai lapisan pelindung korosi masih sangat terbatas. Perkembangan dalam sistem powder coating hijau terutama difokuskan pada kos dan kesihatan, persekitaran dan masalah keselamatan daripada pembangunan produk baru dan penilaian prestasi produk. Tujuan utama dari projek ini adalah untuk mengetahui dan membandingkan kesan daripada penyelesaian dari pH yang berbeza, air laut dan air paip laju korosi pada baja karbon poliester TGIC tidak dilapisi dan baja karbon dilapisi dari komposisi yang sama dan dimensi. Kesan dari parameter pada kekuatan tarik dan had-had yang signifikan atau lapisan poliester TGIC-bebas juga telah diselidiki. Laju korosi ditentukan dengan menggunakan kaedah berat badan selepas beberapa siri ujian perendaman dan semua ujian ini dilakukan sesuai dengan ASTM G31. Setelah uji perendaman, baik spesimen dan dilapisi menjadi sasaran ujian tarik sesuai dengan ASTM-E 8M. Keputusan makmal menunjukkan bahawa sistem lapisan hijau berkesan dalam mengurangkan laju korosi dan meningkatkan kekuatan tarik baja karbon di bawah paparan penyelesaian rentang pH 3-12, kran air, dan air laut. Juga, TGIC-Percuma Polyester Coating menunjukkan daya tahan khususnya tinggi dalam larutan asid (penyelesaian pH 4 dan bawah) dan paip air.

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CHAPTER 1

INTRODUCTION

1.1 Background Study

Carbon steel remains the economic choice of materials for construction of large structures. Over the years, numerous protection schemes involving organic, inorganic, metallic coatings and combinations thereof have been successfully developed to extend the service life of these structures in corrosive environments. Among the corrosion prevention solutions, powder coating, a type of dry organic coating system is claimed to be by far the least hazardous coating system.

Some of the most significant environmental friendly features of powder coating are such as near zero volatile organic compounds (VOC) emission and less hazardous waste production during the mechanical finishing process. No VOC are released due to the fact that solvents are not used throughout the coating process and the coating equipment can be cleaned with compressed air instead of solvent, hence creating less hazardous residues.

Although considered as a safe system, the latest finding of mutagenicity of Triglycidyl isocyanurate (TGIC), a compound widely used in the powder coating industry to produce films with excellent durability, hardness, flexibility and surface properties, however, affects adversely the toxicological image of exterior powder coatings. According to EHS Reference List adopted by the Department of Environment Malaysia which is based on the European Classification, TGIC is a class 2 mutagen and an acute dermal and respiratory toxin.

The discovery of TGIC debilitating toxicology encourage chemist to work on finding other non-mutagenic formulae for existing powder coating chemical composition. And, in late 1980s, the first TGIC free.cross linkers for polyester resins were introduced.

The cross-linking is an esterification process between the β- hydroxyalkylamide groups from the cross-linker and the carbonyl groups from the polyester binder to produce a cross-link intermediate and water as by-product (Refer Figure 1.1). The final product is non-toxic and can be considered as ecologically safe.

Nowadays, the applications of TGIC-free coated carbon steel in building industry is on the rise, mainly because it is less costly, effective in corrosion prevention and create least environmental hazards. However, available literature investigating the product performance this green coating layer is still very deficient. It has been claimed that the development in the powder coating industry mainly has focused on cost and health, environment and safety issues rather than new product development and product performance evaluation.

In this paper, the effectiveness of TGIC-free polyester coating in serving as a protective layer to carbon steel surface from corrosion under several corrosion tests parameters is to be studied. For TGIC-free polyester coating which is designed mainly for exterior applications, the corrosion rate is in fact a very important aspect to be accessed especially if the coating system is to be applied at industrial areas conflicted with pollution problems such as acid rain, beach area where the structure is to be attacked by seawater, or areas in warm climate all year long. The research is done to the purpose of investigating the corrosion effect caused by different corrosive conditions to the coating and it is hoped that this paper can do some contributions to product improvements of powder coating technology.

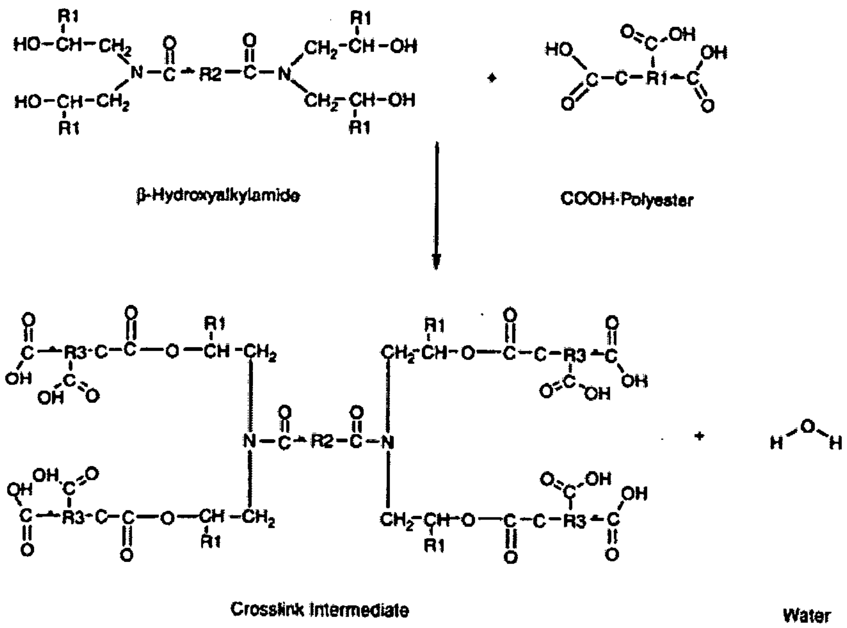

Figure 1.1: The cross linking between β- hydroxyalkylamide and carbonyl-polyester
(Source: Tracton, A., 2006)

1.2 Problem Statement

The development in the powder coating industry mainly has focused on cost and health, environment and safety issues. Comparatively less researches regarding to product development and technical evaluations of this green technology are available compared to other liquid-based coating system. The number of literatures focused on the technical evaluation of TGIC-free polyester coating as a corrosion protective layer is very limited.

TGIC-free polyester coating is designed for outdoor applications. This new branch of powder coating system which is widely used as a protective layer to outdoor components of a building such as steel gate, inspection chamber and manholes cover is constantly exposed to changing outdoor environments throughout its service life. Hence, it is especially important to learn the effects of various corrosive parameters on the corrosion rate and tensile strength of TGIC-free polyester coated steel so that to confirm compliance with its designated applications, to study the limitations of this coating system, and hence to evaluate the coatings for various services.

1.3 Objectives

The objectives of this study are:

1. To investigate and compare the effects of solutions of different pH , seawater and tap water on the corrosion rates of
    a. TGIC-free polyester coated carbon steel
    b. Uncoated carbon steel

   of the same composition and dimension
2. To determine the effect of these parameters on tensile strength of coated and uncoated carbon steel by conducting tensile tests.
3. Discuss the significance or limitations of TGIC-free polyester coating in preventing corrosion under these parameters.

1.4 Scope of Study

This study mainly focuses on the investigation of the corrosion rates of coated and uncoated (as control) carbon steel after exposing to solutions of different pH, seawater and tap water. Different concentrations of acid chloride and sodium hydroxide will be mixed to produce solutions of different pH. The coating to be used is TGIC-free polyester coating, a green coating system designed for external applications.

The corrosion rate of each tested specimens are then being determined by weight loss method and evaluated by tensile test. The results obtained were analyzed using graphs and tables. Discussion were mainly focused on the effect of different test solutions to the specimens, and the significant or limitations of TGIC-free polyester coating in serving as a protective layers under those corrosive environments.

CHAPTER 2

LITERATURE REVIEW

2.0 Introduction

This chapter is divided into two parts. The first part elaborates about powder coating technology, its green features and the development of TGIC – free polyester coating with its technical evaluation. The second part reviews on issues regarding corrosion, including the three common outdoor corrosion inducive factors, namely pH, salinity and elevated temperature and the related ASTM designations regarding to accelerated corrosion tests for coating system.

2.1 Pollution Problems Associated with Conventional Coating Methods

At present, one of the major environmental concerns of the coatings industry is the emission of volatile organic compounds (VOCs), which react in the presence of sunlight to create photochemical ozone or smog. VOC-containing solvents used in the formulation of conventional liquid coatings evaporate during application and curing. VOCs are also released during cleanup operations, which remove paint from painting equipment, paint lines, and spray booth surfaces.

Paint wastes are another environmental priority for the coatings industry. These wastes include paint overspray, defective coatings removed from parts, and wastes generated during colour changeovers. Reformulated coatings and newer coating application equipment can also reduce or eliminate some of these waste

Environmental concerns, together with the increasing costs of organic chemicals and metals (zinc, chromium, etc.) are leading to changes in the formulation of organic coatings. Coating formulators and users are seeking alternative materials to reduce or eliminate use of volatile solvents and heavy metals, and generation of paint residues and wastes.

2.1.1 Powder Coatings and Its Environmental Benefits

Powder coating technology uses dry resin powders for coating substrates with thermoplastic or thermoset films. The coating is formed after a layer of powder is applied with a powder coating spray gun or fluidized bed tank to the substrate and heated, thereby melting the powder. It is applicable for outdoor furniture manufacturing, architectural and building industries all use powder coatings. A major driving force in the growth of powder coatings is attributed to increasingly stringent environmental regulations (Major, 1992)

Powder coatings are applied as a dry material and they contain very little, if any, Volatile Organic Compounds (VOC). The raw material is literally a powder, mixed dry, extruded, and ground into the final material. Hester, C.I. and Nicholson, R.L. (1989) present the following example to show the potential VOC reductions is achievable with powder coatings. A large conventional coating facility cavers 12 million ft/yr of substrates with 1.2 m thick coats. The plant uses a VOC treatment system with 70 percent capture efficiency. Emissions of VOC are approximately 38 tons/yr. By comparison, a powder coating facility using electrostatic application of polyester-urethane resins will emit only 0.6 tons/yr of VOCs, and avoids the need for emission control equipment. Therefore, it can be conclude that the increased use of powder coatings, as an alternative to liquid solvent-based coatings, represents a significant reduction in emissions of VOC's.

2.2 Polyester Powder Coatings

Polyester powder coatings feature characteristics of long-term exterior durability, high performance mechanical properties and heat resistance and it makes up approximately 36% of world powder production. Polyester powder is widely used for decorative components where good resistance to the ultraviolet rays from sunlight is important. Most coatings used on buildings use TGIC-polyester powders. TGIC resins produce films with excellent surface properties such as hardness, flexibility, exterior durability, and corrosion and overbaking protection.

2.2.1 Mutagenicity of TGIC

According to EHS Reference List adopted by the Department of Environment Malaysia which is based on the European Classification, TGIC is a class 2 mutagen and an acute dermal and respiratory toxin with the following mutagenicity:

- R 20/22 (harmful by inhalation and if swallowed),
- R 36/37/38 (irritating to the eyes, respiratory system and skin),
- R40 (possible risk of irreversible effects) and
- R43 (may cause sensitisation by skin contact)

2.2.2 TGIC-free Polyester Powders

At the end of the 1980s a new beta-hydroxyl alkyl amide type of crosslinker , an esterification product between the reaction of 1 mol of beta-hydroxyl alkyl amide group from the crosslinker and 2 mol of carboxyl groups from the binder appeared in the market under the name Primid which, from a toxicological point of view, is a completely safe material and can be considered non-toxic. However, compared to TGIC, Primid is proved to have poorer outdoor durability.

Misev, T.A. and van der Linde, R. (1998) studied the extensive research works on chemistry, production and application technology of TGIC – free powder coatings and tries to extrapolate the tendencies in the years to come in order to predict the achievements and the impacts on the paint industry. In their report, it is summarized that the new toxicologically-safe chemistry which that has been developed for exterior applications will preserve the image of powder coatings as the most secure coatings from environmental and toxicological points of view.

2.2.3 Architectural Applications

Architectural coatings are applied on site to interior or exterior surfaces of residential, commercial, institutional, and industrial buildings. They are applied for protection and appearance, and cure at ambient conditions. The architectural market, which developed from coating window and door frames in the early to mid-1970s, expands to structural beams and panelling for both internal and external use. TGIC-free powders become available by 1991 for exterior applications in Europe. This product segment is unique because of its scale and use in both interior and exterior environments, requiring specialized powder coating chemistries. The availability of a wide number of colours, improvements in applying powder coating to aluminium profiles and sheets, and increased quality of powder coatings for external applications were decisive for the increasing importance of powder coatings in architecture. Environmental regulations were the "driving force" for the use of powder coatings in this market segment.

2.2.4 Technical Evaluation

The ability of a coating to perform as intended could be tested in the field by exposing both coated and uncoated metal specimens to its intended service conditions for a period of time, usually not less than six month and measure their corrosion rate at the end of this period. The major advantage of field test is that it is done in a real field condition and hence, is believed to yield realistic results. However, the specimens may be subjected to other disturbances which are not measured as one of the corrosion-inducive parameters. Another disadvantage is that the recorded corrosion in real field study is the result of a combination of factors and the effect of individual parameter is hard to determine.

One of the successful real field study is completed by Le Thi, H. L., and Pham, T. S. in 2002. They investigated the effect of various environmental factors on carbon steel atmospheric corrosion by exposing a number of carbon steel specimens at testing site all over Vietnam in the period 1995 – 2000. In their study, it is show that the corrosion rate increases with increasing relative humidity, chloride concentration in the air, time of wetness (TOW) and decreasing air temperature but how much do each factor has contributed to the corrosion is hard to justified.

There are only limited studies done by researcher regarding the technical evaluation of TGIC –free polyester coating. Bjordal, M. *et al* (2006) are among the few that has evaluated the performance of powder coatings on hot-dip galvanized steel by testing in a 5-year field exposure to marine and industrial atmospheres, and, in accelerated tests. The aim of heir study was to assess the quality of such coating systems in corrosive environments and to establish criteria for how to obtain good quality. Both the field and experimental test data demonstrates that polyester powder coatings are a good alternative to wet paint as top coat on hot-dip galvanized steel. In the same paper, Bjordal, M. *et al* also compare between primide, the market name for TGIC-free curing agent for polyester powder coating, and TGIC curing agent in terms of creep deformation preventation . The result of the tests is showed in Figure 2.1 whereby the average size of scribe creep formed after the two systems manufactured by three different workshops subjected to real field marine and industrial environment or five years, and standard accelerated laboratory tests cyclic tests. From a performance perspective there seems to be no problem in replacing the toxic TGIC curing agent of polyester with primide.

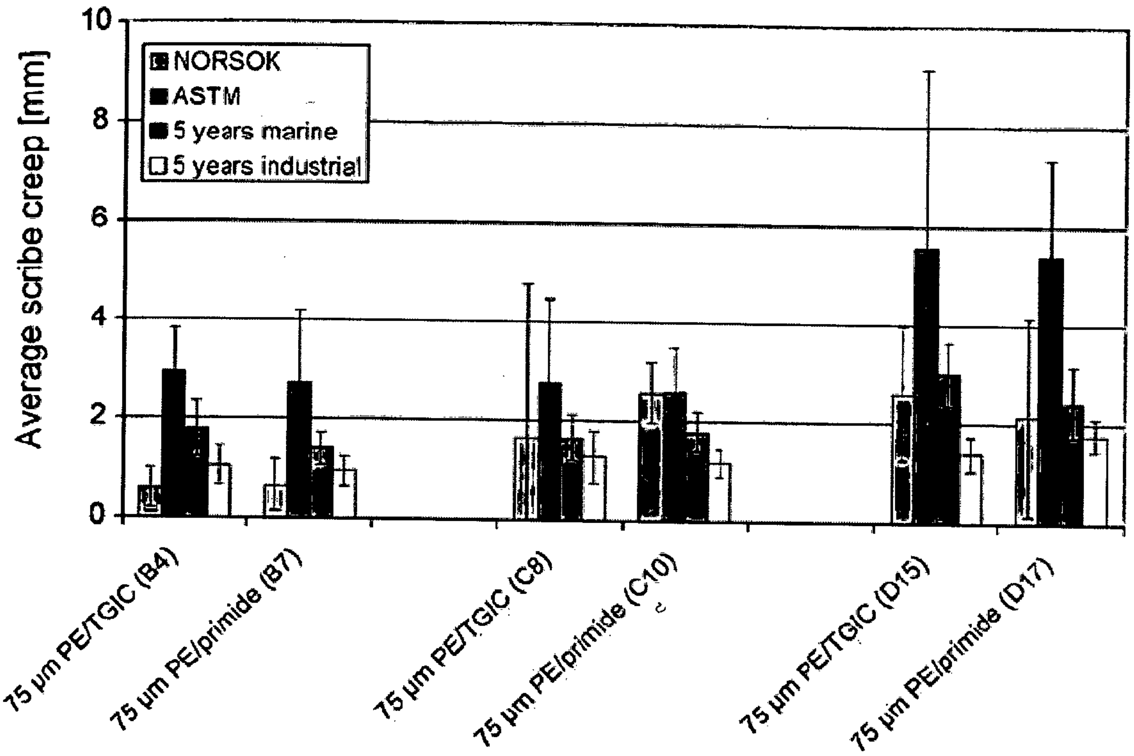

Figure 2.1: Comparison of polyester powder coatings hardened with TGIC or primide on phosphate HDG steel. Systems B4 and B7 are from the same workshop, similarly for C8 and C10, and D15 and D17.

(Source: Bjordal, M. et al 2006)

2.3 Common Outdoor Corrosion Inducing Factors

2.3.1 pH

Baboian, R. (2005) claimed that the most important single variable affecting corrosivity is pH. The relationship between pH and corrosion rate of uncoated mild steel, is shown in Figure 2.1.at a pH below 4, corrosion increases rapidly with decrease in pH. In the pH range 4 to 9, changes in pH have a relatively minor effect on corrosivity to steel. Above pH 9, corrosivity decreases as pH increases.

A change in pH could be caused by various environmental factors such as water pollutions, acid rain, and industrial discharge. According to Jones, D. A.(1996), many of the common constructional metals have increased corrosion in low pH solutions due to the higher availability of oxidising H+ and solubility of oxides while other show increased corrosion at very alkaline pH values.

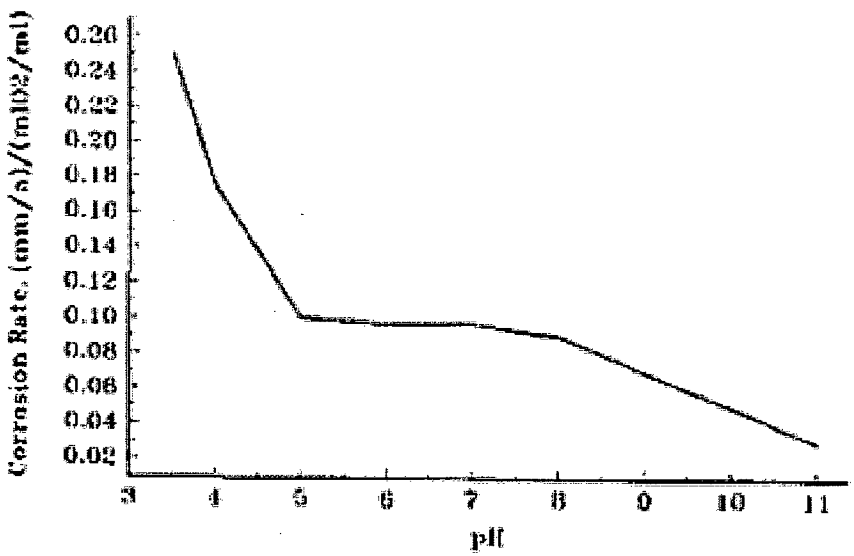

Figure 2.2: The effect of pH on the corrosion rate of carbon steel

(Source: Baboian, R. ,2005)

2.3.2 Dissolved Oxygen (DO)

The corrosion of steelworks in water distribution system can be either general, i.e., occurring more or less uniformly over large portion of the surface, or localised. From a corrosion standpoint, a significant component in tap water is dissolved oxygen (DO) from ambient air.

According to Roberge. R. R. (2008), oxygen acts both as a cathodic depolarizer and an oxidizer. As a cathodic depolarizer, DO can remove hydrogen from the cathode during electrochemical corrosion and accelerate the corrosion attack. As an oxidizer, DO can be reduced on the metallic surface and participate directly to the electrochemical process.

The effect of DO in tap water on the corrosion of carbon steel is illustrated in Figure 2.3. It should be noted that an increasing temperature is accompanied by an increase in corrosion rate of the steel due to faster reaction kinetics.

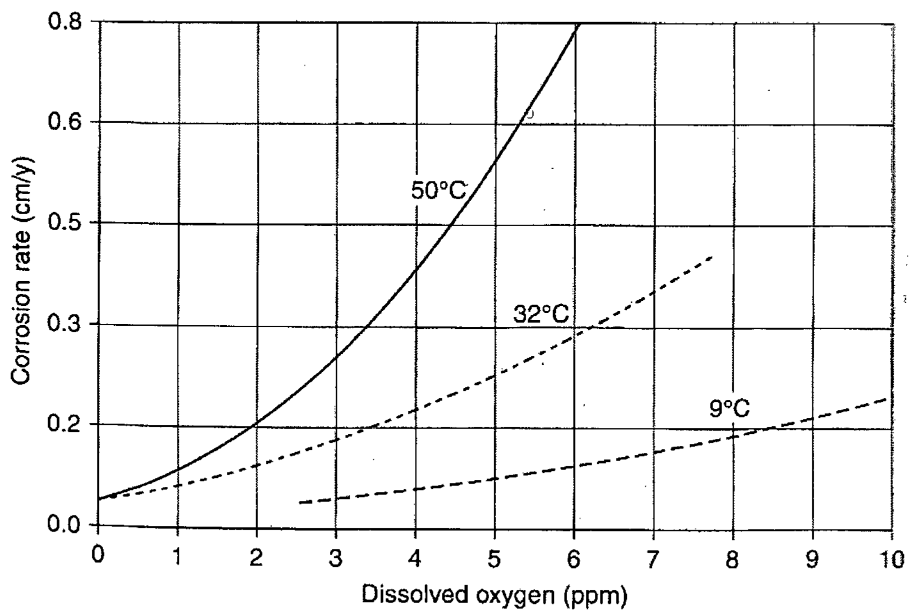

Figure 2.3: Effect of Dissolved Oxygen on the Corrosion Rate of Low-Carbon Steel in Tap Water at Different Temperatures

(Source: Roberge. R. R. , 2008)

2.3.3 Salinity

Sodium Chloride, NaCl is a type of salt which do not appreciably alter the pH when dissolved in water. NaCl present in plentiful amount in seawater brackish waters and many chemical process waters. The schematic effect of NaCl concentration on corrosion rate of iron in aerated room-temperature solutions is shown in figure 2.2.

The initial increase in corrosion rate is due to enhanced solution conductivity. However, further increase in dissolved salt concentration (beyond 3% of NaCl) decreases the solubility of dissolved oxygen and hence, reduces the corrosion rate.

An NaCl solution of about 3.5% is sometimes used to simulate seawater in the laboratory. However, Jones, D.A (2005) claims that such solutions are often more aggressive than natural seawater, especially towards carbon steel. Another difference is that in real coastal and seawaters, factors such as elevated temperature, dissolved oxygen content, currents, biological organisms and pollutants can increase corrosion rates. Synthetic seawater made up from laboratory chemicals is available as standard, but corrosively is not likely to match any particular seawater site quantitatively.

Typical steel structures exposed to saline environments are such as marine piles, offshore structures, vessels, etc.