GRAPHENE - BASED COATING

EFFECTIVE WAYS OF PREVENTING CORROSION

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LIST OF ABBREVIATIONS

ACM	-	Applied Corrosion Monitoring
ASTM	-	American Society for Testing and Materials
ATH	-	Aluminium trihydrate
BF_3	-	Boron trifluoride
C	-	Capacitance
Cl^-	-	Chlorine ion
Cu	-	Cuprum
CNT	-	Carbon nanotube
CP	-	Cathodic protection
EIS	-	Electrochemical impedance spectroscopy
e.g.	-	For example
EG	-	Epoxy coating containing graphene nanoplatelets
FG	-	Functionalised graphene
EGO	-	Epoxy coating containing graphene oxide
FGO	-	Functionalised graphene oxide
FLG	-	Few-layer graphene
GNP	-	Graphene nanoplatelets
GNS	-	Graphene nanosheets
GO	-	Graphene oxide
GOPC	-	Graphene oxide polymer composite
HCl	-	Hydrochloric acid
HNT	-	Halloysite
H_2O	-	Water
H_3PO_4	-	Phosphoric acid
H_2SO_4	-	Sulphuric acid
$KMnO_4$	-	Potassium permanganate
MMT	-	Montmorillonite

$NaNO_3$	-	Sodium nitrate
Ni	-	Nickel
O_2	-	Oxygen gas
OCP	-	Open circuit potential
PVA	-	Polyvinyl alcohol
PU	-	Polyurethane
SHE	-	Standard hydrogen electrode
SO_2	-	Sulphur dioxide
SO_3	-	Sulphur trioxide
SCE	-	Saturated calomel electrode
SST	-	Salt spray test
W	-	Warburg impedance
WE	-	Working electrode

LIST OF SYMBOLS

C_{dl}	-	Double-layer capacitance
I_{corr}	-	Corrosion current density
K_{sp}		Solubility constant
R_{corr}	-	Corrosion rate
R_{ct}	-	Charge Transfer Resistance
R_p	-	Polarisation resistance
$\|Z\|$	-	Impedance

PREFACE

This book is the culmination of nearly four years of work I have done on epoxy-based nanocomposite coatings. Honestly, I could not produce this book without a strong support group especially from my family and committed team. I have completed my doctorate study successfully with flying colour after went through many obstacles and difficulties. I succeed to complete my doctorate study with flying colors.

This book contains comprehensive information about the recent development of epoxy nanocomposite coating, property relationships, and its applications. A corrosion prevention method with a detailed explanation on the mechanism of anti-corrosion coatings has been inclusively discussed. The detailed description of graphene-based coatings with ample research findings has been thoroughly deliberated. A more in-depth study on the effect of graphene-based nanofillers on anticorrosion performance is highlighted and successfully proved through scientific evidence.

I hope that this book will be valued and appreciated by students and researchers from the same field of studies.

ACKNOWLEDGEMENT

In the name of Allah The Most Gracious and Most Merciful. Within the salawat and salam to Prophet Muhammad S.A.W. Alhamdulillah. Thanks to Allah S.W.T. the Almighty for His generous blessing and the undying strength bestowed to us to publish this book. Special thanks extended to Prof. Dr. Azman bin Hassan and Assoc. Prof. Dr. Zurina binti Mohamad for their germinal ideas, invaluable guidance, continuous encouragement and constant support in making this research possible.

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CHAPTER 1

INTRODUCTION

Corrosion is a problem of great economic importance to industry and results in potential danger to humans. Deterioration due to corrosion is one of the major causes of metal component failures (Hasan et al., 2018). It cannot be fully prevented, and thus corrosion control strategies focus on slowing the kinetics and/or altering its mechanism. The widespread use of metals in corrosion prone environments initiates comprehensive research focused on developing coatings that protect against corrosion. Different strategies are utilised in various fields such as marine equipment, pipelines and construction to attenuate the intensity and severity of corrosion. Consideration of basic requirements such as durability, high performance, inexpensive, easy application and eco-friendly material is necessary for the selection of coating material (Gu et al., 2020). The uses of polymers that have long-chain carbon linkages can block large areas of the corroding metal surfaces upon adsorption.

Metallic materials have significant importance in industry and research because of their excellent mechanical and processing properties, and are extensively used in various industries such as construction, transportation and marine (Xu et al., 2019). Unfortunately, metallic materials can be easily corroded as a result of environmental effects. The corrosion of metals involves a series of electrochemical reactions in oxygen-containing environments and deteriorates the performance of metallic components accordingly. In recent years, much more attention has been paid to metallic corrosion because of its adverse effect, including economic losses, environmental contamination and safety problems.

Aqueous corrosion represents the most troublesome forms of corrosion that exist in engineered structures when in contact with seawater as a destructive attack to structures, ships and other equipment used in seawater services (Zhang et al., 2019). Rising incidences of corrosion-induced premature degradation of metallic infrastructure make corrosion a pervasive issue across the industry. From the simplest fastener nail to huge underground pipes, all metallic substrates have a natural tendency to corrode in the presence of H_2O, O_2, Cl^-, etc. It is not prudent to quantify corrosion only in terms of gross domestic product loss, as it also leads to huge safety concerns, adverse health effects, loss of life, resources and more.

Although corrosion may be inevitable, its protection can possibly be done through cathodic protection (Qian et al., 2017), protective coatings (Moazeni et al., 2013), corrosion inhibitors (Goyal et al., 2018) or any combination thereof. The application of anticorrosive coatings seems to be a well-established approach for separating metals from an aggressive corrosive environment.

Epoxy resins are widely used in advanced composites coating due to its excellent chemical and electrical resistance, affinity to heterogeneous materials, great impregnation, and adhesion to fibre reinforcement, resulting in an excellent mechanical performance, low shrinkage on a cure, as well as ease processing. These technical benefits balance their relatively higher costs compared to other thermosetting polymers for a particular application (Toldy et al., 2011). Epoxy coatings are generally used to protect the metal substrate against corrosion by two functions. First, they act as a physical barrier layer to control the ingress of deleterious species. Second, they can serve as a reservoir for corrosion inhibitors and other additives to protect the metal surface from the attack by different species such as chloride ions.

Although epoxy has many excellent characteristics, it has few drawbacks; brittleness, low fracture toughness and low flame retardancy. Moreover, epoxy coatings are thwarted by their susceptibility to damage by surface abrasion and wear (Wang et al., 2019), and poor resistance to the initiation and propagation of cracks (Sapronov et al., 2019). These processes impair their appearance and mechanical strength, as well as initiate localised defects that can also act as pathways accelerating the permeation of water, oxygen and aggressive species onto the metallic substrate, resulting in its localised corrosion. Therefore, to enhance the durability of epoxy-based coatings, the incorporation of nanofiller as a protective barrier or inhibitor is inevitable. The inclusion of nanofiller into epoxy resin addresses the above bottleneck and further augments its anticorrosion performance.

Nanoparticles fillers have been used to overcome the disadvantages of the epoxy coating due to its outstanding properties (Pourhashem et al., 2017; Rajitha et al., 2020). Nanofillers tend to occupy tiny holes defects formed from local shrinkage during curing of epoxy resin and they act as a bridge interconnecting more molecules. A decrease in total free volume and surface area of grain boundaries, as well as an increase in the cross-linking density of the epoxy resin matrix, can mitigate blister or delaminate of epoxy coating (Nguyen-Tri et al., 2018). Therefore, the durability of epoxy coatings can be further enhanced by the incorporation of nanoparticles filler when subjected to aggressive media.

The development of nanotechnology in the corrosion protection of metals has gained traction in recent years, because the use of nanotechnology has proven to facilitate waste hazardous minimisation, which has been restricted by environmental regulations (Ijaola et al., 2020). The most crucial concern regarding anticorrosion coatings is finding an appropriate alternative to a toxic and environmentally harmful corrosion inhibitor. The use of natural resources and non-toxic inhibitive pigments, for instance, graphene and montmorillonite (MMT), spurred intense interest in industries to replace existing harmful and high toxicity inhibitive pigments such as strontium or zinc chromates (Krishnan et al., 2018). Therefore, nanocomposite coating has fascinated the number of consideration as a simple and cost-effective method of enhancing coating properties by the addition of a small amount of properly designed and dispersed nanoparticle fillers (TabkhPaz et al., 2018).