EFFECT OF CURRENT PROFILE AND EPOXY POTLIFE ON SURFACE RESISTIVITY OF ELECTRODEPOSITED EPOXY COATING

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in partial fulfillment of the requirements for the degree of
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DECLARATION

I declare that this master project entitled "Effect of Current Profile And Epoxy Potlife on Surface Resistivity of Electrodeposited Epoxy Coating" is the result of my own research except as cited in the references. The master project has not been accepted for any degree and is not concurrently submitted in candidature of any other degree.

Signature :...

Name :...

Date :...

APPROVAL

I hereby declare that I have read this master project and in my opinion this master project is sufficient in terms of scope and quality as a partial fulfillment of Master of Manufacturing Engineering (Industrial Engineering)

Signature :..

Supervisor Name :..

Date :..

DEDICATION

All the praises and thanks to Allah S.W.T for His Guideness and Enlightment.

This thesis is dedicated to those who have supported and inspired me throughout this journey. To my dear mother, Khepesah Binti Yusoff, your unconditional love and sacrifices have laid the foundation for all my achievements. Your wisdom and strength are the bedrock of my success. To my beloved wife, Noorakiah Binti Mat Razali, your endless love, patience, and support have been my greatest strength. You have been my pillar of resilience and my source of inspiration. To my three wonderful children, your presence brings immense joy and motivation. You remind me every day of the importance of perseverance and dedication. To my beloved siblings, your steadfast love and encouragement have been a continual source of strength during this journey. To my cherished friends and fellow comrades, thank you for standing by my side through the challenges and triumphs. Your companionship and support have been essential in this journey.

ABSTRACT

Electrodeposition (EPD) is a widely utilized method for applying epoxy coatings due to its ability to precisely control coating thickness and uniformity, essential for consistent performance in various applications. This study examines the impact of current-voltage profiles on the surface resistivity of electrodeposited epoxy coatings, which are critical for applications such as electrical insulation, electronics packaging, and corrosion prevention. Despite their significance, the precise correlations between electrodeposition parameters and surface resistivity have not been fully established. We investigated this relationship using characterization techniques like the Four-Point Probe method, Ultraviolet-Visible (UV-Vis) Spectrophotometry, and Field Emission Scanning Electron Microscopy (FESEM), alongside a design of experiments (DOE) approach employing Central Composite Design (CCD) in the Response Surface Methodology (RSM) framework. Results indicated that the current-voltage profile significantly influences surface resistivity, with optimal profiles achieving a coating thickness of 153.26 µm at 60V and 1-hour pot life, and resistivity values of 758.2 kΩ-cm/□ at 30V, 798.2 kΩ-cm/□ at 40V, and 818.0 kΩ-cm/□ at 60V for 1-hour pot life. RSM analyses confirmed significant effects of pot life and voltage on thickness and resistivity. These findings are crucial for industries relying on epoxy coatings for electrical insulation, electronics packaging, and corrosion prevention, as they can achieve improved performance and reliability by adopting the optimal current-voltage profiles identified. This study advances understanding of the relationship between current-voltage profiles and surface resistivity of electrodeposited epoxy coatings, paving the way for materials with customized resistivity properties.

KESAN PROFIL ARUS DAN MASA GUNA CAMPURAN EPOKSI TERHADAP RINTANGAN PERMUKAAN SALUTAN EPOKSI YANG TERDEDAP ELEKTRODEPOSISI

ABSTRAK

Elektrodeposisi (EPD) adalah kaedah yang banyak digunakan untuk menerapkan salutan epoksi kerana keupayaannya untuk mengawal ketebalan dan keseragaman salutan dengan tepat, yang penting untuk memastikan prestasi konsisten dalam pelbagai aplikasi. Kajian ini meneliti kesan profil voltan arus terhadap rintangan permukaan salutan epoksi yang didepositkan secara elektro, yang penting untuk aplikasi seperti penebat elektrik, pembungkusan elektronik, dan pencegahan kakisan. Walaupun kepentingannya, hubungan tepat antara parameter electrodeposisi dan rintangan permukaan belum sepenuhnya ditetapkan. Kami menyiasat hubungan ini menggunakan teknik pencirian seperti kaedah Probe Empat Titik, Spektrofotometri Ultraviolet-Nampak (UV-Vis), dan Mikroskopi Imbasan Elektron Pancaran Medan (FESEM), bersama dengan pendekatan reka bentuk eksperimen (DOE) menggunakan Reka Bentuk Komposit Pusat (CCD) dalam rangka Kerja Metodologi Permukaan Respons (RSM). Keputusan menunjukkan bahawa profil voltan arus secara signifikan mempengaruhi rintangan permukaan, dengan profil optimum mencapai ketebalan salutan 153.26 µm pada 60V dan masa guna campuran 1 jam, dan nilai rintangan 758.2 kΩ-cm/□ pada 30V, 798.2 kΩ-cm/□ pada 40V, dan 818.0 kΩ-cm/□ pada 60V untuk masa guna campuran 1 jam. Analisis RSM mengesahkan kesan ketara masa guna campuran dan voltan terhadap ketebalan dan rintangan. Penemuan ini adalah penting untuk industri yang bergantung pada salutan epoksi untuk penebat elektrik, pembungkusan elektronik, dan pencegahan kakisan, kerana mereka dapat mencapai prestasi dan kebolehpercayaan yang lebih baik dengan mengadopsi profil voltan arus optimum yang dikenal pasti. Kajian ini memajukan pemahaman mengenai hubungan antara profil voltan arus dan rintangan permukaan salutan epoksi yang didepositkan secara elektro, membuka jalan untuk bahan dengan sifat rintangan yang disesuaikan.

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TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF ABBREVIATIONS

UTeM	-	Universiti Teknikal Malaysia Melaka
EPD	-	Electrophoretic Deposition
UV-Vis	-	Ultraviolet-Visible
FESEM	-	Field Emission Scanning Electron Microscopy
RSM	-	Response Surface Methodology
ANOVA	-	Analysis of Variance
EDS	-	Energy-Dispersive X-ray Spectroscopy
WDS	-	Wavelength-Dispersive X-ray Spectroscopy
Rs	-	Sheet Resistance
DGEBA	-	Diglycidyl Ether of Bisphenol A
CCD	-	Central Composite Design
DOE	-	Design of Experiment

LIST OF SYMBOLS

µm	-	micrometer
kV/mm	-	Kilovolts per millimeter
t	-	Thickness
V	-	Voltage
g/mL	-	grams per milliliter
°C	-	Degrees Celsius
%	-	Percentage
nm	-	nanometer
kg	-	kilogram
m	-	meter
mm	-	millimeter
nm/min	-	nanometer per minute
A	-	Ampere
Pa	-	Pascal
kg/mol	-	kilograms per mole
g/mol	-	grams per mole
W	-	Watt
m^2	-	square meter
s	-	second
J	-	Joule
kΩ-cm/□	-	kiloohm-centimeter per square
mΩ-cm/□	-	miliohm-centimeter per square
C	-	Carbon
O	-	Oxygen
Cl	-	Chlorine

LIST OF APPENDICES

CHAPTER 1

INTRODUCTION

This chapter contains a detailed overview of the project's background, the problem statement, the research objective, the scope of the research, and the scope of the research and the organization of the report. This study's significance is entirely justified. In comparison, the breadth of the investigation in this chapter protects the depth of the inquiry.

1.1 Background

The field of materials science and engineering continuously seeks to enhance the performance and functionality of coatings, which are critical for protecting and improving the properties of various substrates in industrial applications (J. Zhang et al., 2019). Among these coatings, epoxy-based materials stand out due to their exceptional mechanical strength, chemical resistance, and superior electrical insulating properties (Seidi et al., 2020).

Epoxy coatings are extensively employed across various industries as a means of mitigating corrosion and non conductivity purpose. Epoxy coatings offer a barrier that shields the metal surface, thereby obstructing any interaction with the surrounding environment and inhibiting corrosion (Song et al., 2021). Nevertheless, the efficacy of the epoxy coating procedure relies on various elements, including surface preparation, application technique, curing time, and climatic conditions.

Thoroughly preparing the surface is crucial for achieving success in the epoxy painting procedure. To ensure optimal adhesion of the epoxy coating, it is imperative to meticulously cleanse the metal surface, eliminating any traces of dirt, oil, or other impurities that could potentially hinder the bonding process (Seidi et al., 2020). To enhance adhesion, it may be necessary to sand or blast the surface in order to generate a rougher texture.

Electrodeposition (EPD) is a widely employed technique for applying epoxy coatings (Pingale et al., 2021). This EPD process allows for precise control over the thickness and uniformity of the coating, which is essential for ensuring consistent performance across a wide range of applications (Vidal et al., 2019). The process involves the application of a current or voltage to induce the deposition of epoxy resin onto a conductive substrate, resulting in a solid, adherent coating upon curing (Mureşan et al., 2021).

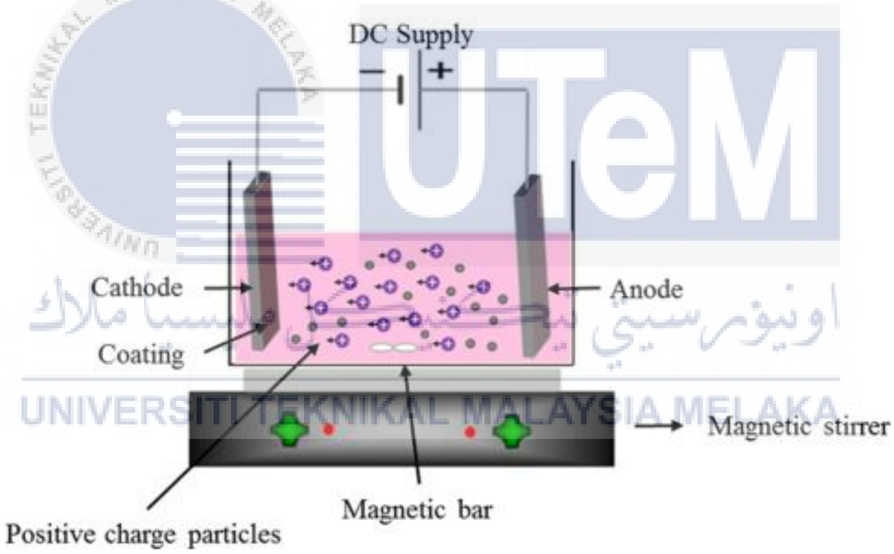

Figure 1.1 Schematic for Electrodeposition (Aghili et al., 2021)

In order to achieve optimal coating performance and quality, it is important to conduct a comprehensive study on the preparation of EPD suspensions for epoxy coatings. The proper preparation of the suspension ensures the stability, uniformity, and distribution of the particles or colloids in the suspension, which has a direct impact on the deposition and creation of the film during EPD (Gaafar et al., 2022). In order to get a uniform and flawless coating, it is necessary to thoroughly examine and optimise many factors, such as particle size, concentration, surface charge, choice of dispersant, and selection of solvent. To achieve precise control over layer thickness, adhesion, porosity, and surface roughness, it is necessary to comprehend the interplay between the various components of the suspension and how these interactions impact the properties of the coating (M. R. Rahman et al., 2022).

The dielectric properties of these coatings, such as permittivity, dielectric strength, and loss tangent, are of particular interest as they determine the material's ability to insulate against electrical currents and its behavior in the presence of electric fields (Aghili et al., 2021). These properties are not only intrinsic to the epoxy material but are also significantly influenced by the conditions under which the coating is deposited, including the current-voltage profile used during the electrodeposition process (Pingale et al., 2021).

The current-voltage profile, also known as the I-V characteristic, is a relationship that defines how the current through a device or material depends on the applied voltage. It is a fundamental concept in electrical engineering and materials science, as it provides insights into the electrical behavior of materials and devices (Caprara & Ciotti, 2022).

The current-voltage profile refers to the specific pattern of current and voltage applied during the electrodeposition. It can vary in terms of magnitude, duration, and waveform (e.g., constant, pulsed, or ramped) (Murbach, 2021). This profile is a critical parameter as it affects the microstructure, thickness, and cross-linking density of the resulting epoxy coating, all of which are directly related to the material's dielectric properties (Pingale et al., 2021).

1.2 Problem Statement

The dielectric characteristics of electrodeposited epoxy coatings are crucial in determining their efficacy for applications such as electrical insulation, electronics packaging, and corrosion prevention. Epoxy coatings are widely used in various industries due to their excellent mechanical and chemical properties. They provide a protective layer against corrosion, wear, and other environmental factors. However, the effectiveness of the coating as a dielectric is crucial in certain applications, such as in electrical insulation (Seidi et al., 2020). Nevertheless, the precise connections between the electrodeposition parameters and the resulting dielectric characteristics have not been completely defined.

The current-voltage profile during the electrodeposition process can affect the dielectric properties of the coating (Pingale et al., 2021). The quality of the coating depends on various factors, including the current-voltage profile during the electrodeposition process. The current-voltage profile can affect the thickness, uniformity, and adhesion of the coating, which can, in turn, affect the surface resistivity of the coating. Therefore, it is essential to understand how the current-voltage profile affects the surface resistivity of the electrodeposited epoxy coating.

The problem statement of this thesis is significant because it addresses the need to improve the quality of epoxy coatings as dielectrics. The study aims to identify signs of potential problems with the coating's surface resistivity early on and improve the coating process to make better-quality, longer-lasting coated steel products more efficiently. The research will provide current-voltage curve models for poor and good electrodeposition coating processes in relation to dielectric performance, which can help in predicting the effectiveness of the coating as a dielectric.

1.3 Research Question

The research questions guiding this investigation into the relationship between the electrodeposition process, current-voltage profiles, and the surface resistivity of epoxy coatings are as follows:

a) How does the current-voltage profile during the electrodeposition process affect the surface resistivity of epoxy coatings on mild steel surfaces?

b) What is the relationship between the electric current during the electrodeposition process and the surface resistivity of the cured coatings?

c) Can current-voltage curve models be developed to distinguish between poor and good electrodeposition coating processes in relation to surface resistivity performance?

d) How can understanding the electric current in the coating process be used to predict the effectiveness of the epoxy coatings as surface resistors on mild steel surfaces?

e) What early signs of potential problems with the coating's surface resistivity can be identified through the analysis of current-voltage data, and how can this information be used to improve the coating process?

1.4 Research Objective

The main aim of this research is to propose a systematic and effective methodology to study the relationship between current voltage and surface resistivity using the EPD process. Specifically, the objectives are as follows:

i) To investigate the effect of the current voltage profile on the continuous coating on thickness prepared by the EPD process.

ii) To characterise the surface resistivity of the cured epoxy coating prepared by different applied voltages and epoxy potlife.

iii) To perform design of experiment on the thickness and surface resistivity as function of voltage and epoxy potlife by Response Surface Methodology method.

1.5 Scope of Research

The scope of this research is to analyze the impact of different current-voltage profiles on the surface resistivity of electrodeposited epoxy coatings. This analysis will provide a comprehensive understanding of how variations in current-voltage profiles affect the overall performance and effectiveness of epoxy coatings in electrical insulation application.

Based on first objective, this research aims to investigate the complex correlation between the current-voltage profile and the resulting coating thickness obtained during the electrophoretic deposition (EPD) method. This requires a careful study of various electric currents, deposition times, and voltage levels in order to understand how they affect the thickness of the epoxy coatings on their own and when added together. The study will involve a thorough examination of deposition parameters to determine the ideal conditions that result in consistent and uninterrupted coatings.

Next for the second objective, a significant aspect of this research involves the thorough characterization of the surface resistivity exhibited by the cured epoxy coatings. The study will investigate the impact of different applied voltages and epoxy pot life on dielectric performance in order to gain a full understanding of their influence. The dielectric constant, dielectric strength, and insulation resistance will be thoroughly examined to clarify the complex connections between the deposition circumstances and the resulting surface resistivity.

The research will involve characterising the deposited coatings using techniques such as Four-point probes, Ultraviolet-Visible (UV-Vis) Spectrophotometer, filed emission scanning electron microscopy (FESEM), and methods for measuring thickness. Assessing the mechanical qualities, such as hardness and wear resistance, can provide insights into the performance of the coatings under various EPD settings.

The final objective of the research is to provide practical suggestions for enhancing the surface resistivity of electrodeposited epoxy coatings. By consolidating the results obtained from the analysis of continuous coating thickness and dielectric characterization, the study will propose the most effective combination of applied voltage and epoxy pot life. These recommendations will be based on achieving the desired dielectric performance, while also considering factors such as coating uniformity and feasibility for industrial use.

In summary, the research scopes encompass a comprehensive exploration of the effects of current-voltage profiles on continuous coating thickness, a detailed characterization of surface resistivity, and the subsequent recommendation of optimum