Faculty of Engineering

EVALUATION OF ELECTROPHORETIC DEPOSITION (EPD) OF GRAPHENE NANOPLATELETS (GNP) DISPERSED IN DIFFERENT SOLVENTS ONTO CARBON FIBER VIA AXIOMATIC DESIGN CONCEPT

DINA DZUREMILIA BINTI ASAN

Bachelor of Engineering with Honours
(Mechanical and Manufacturing Engineering)
2020

UNIVERSITI MALAYSIA SARAWAK

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Final Year Project Report ✓

Masters

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DINA DZUREMILIA BINTI ASAN

A dissertation submitted in partial fulfillment
of the requirements for the degree of
Bachelor of Engineering with Honours
(Mechanical and Manufacturing Engineering)

Faculty of Engineering
Universiti Malaysia Sarawak

(2020)

Dedicated to my beloved family and friends

for giving me the strength to keep going

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ABSTRACT

Graphene-related materials (GRMs) have been described as an excellent nano-reinforcement for fiber-reinforced polymers in various engineering applications. The remarkable properties of GRMs, for example, their enormous surface region, high mechanical quality, and low assembling expense carry them to be recognized nano-reinforcements for fiber-reinforced polymers to shape multi-functional and multiscale composites. The axiomatic design concept is used to evaluate the parameters that affect the electrophoretic deposition (EPD) system. This study aims to produce deposition of Graphene nanoplatelets (GNPs) onto carbon fiber (CF) fabric surface using electrophoretic deposition (EPD) method for the time constant (5 mins) with different voltage (5V, 10V, 20V, & 30V) and constant voltage (20V) with different deposition time (5 mins, 10 mins, 20 mins, and 30 mins). With previous research paper justification, the amount of deposited GNPs onto the CF surface is predicted to increase gradually with longer deposited time and voltage applied by observing it under a scanning electron microscope (SEM). Besides, the predicted outcome of the colloidal stability of suspension N, N-dimethylformamide (DMF) as an organic solvent and distilled water (DW) as a non-organic solvent that dispersed with GNPs respectively is determined using UV-Vis Spectrophotometer. The result predicted is that the dispersion of GNPs in N, N-dimethylformamide (DMF) suspension is much better compared in the distilled water (DW) suspension within 1 day period after sonication time.

ABSTRAK

Bahan berkaitan *Graphene* (GRM) telah dibuktikan dalam pelbagai aplikasi kejuruteraan sebagai penguat nano yang sangat baik untuk polimer bertetulang gentian. Sifat GRM yang luar biasa, misalnya, kawasan permukaannya yang sangat besar, kualiti mekanik yang tinggi dan kos pemasangan yang rendah menjadikannya penguat nano yang dikenali untuk polimer bertetulang gentian untuk membentuk komposit pelbagai fungsi dan pelbagai skala. Konsep reka bentuk aksiomatik digunakan untuk menilai pemboleh ubah yang mempengaruhi sistem pemendapan elektroforetik (EPD). Tujuan kajian ini adalah untuk menghasilkan pemendapan nanoplatelet *Graphene* (GNP) ke permukaan kain gentian karbon (CF) menggunakan kaedah EPD untuk pemalar masa (5 minit) dengan voltan yang berbeza (5V, 10V , 20V, & 30V) dan voltan malar (20V) dengan masa pemendapan yang berbeza (5 min, 10 min, 20 min, dan 30 min). Dengan justifikasi kertas penyelidikan sebelum ini, jumlah GNP yang dideposit ke permukaan CF diprediksi akan meningkat secara beransur-ansur dengan masa dan voltan yang diuji kaji dengan lebih lama yang diterapkan dengan memerhatikannya di bawah imbasan elektrom mikroskop (SEM). Selain itu, hasil ramalan kestabilan koloid suspensi *N,N-dimethylformamide* (DMF) sebagai pelarut organik dan air suling (DW) sebagai pelarut bukan organik yang tersebar dengan GNP masing-masing ditentukan dengan menggunakan *UV-Vis Spectrophotometer*. Hasil yang diramalkan adalah bahawa penyebaran GNP dalam suspensi *N,N-dimethylformamide* (DMF) jauh lebih baik dibandingkan dengan suspensi air suling (DW) dalam tempoh 1 hari selepas waktu sonikasi.

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LIST OF ABBREVIATIONS

BET	Brunauer-Emmett-Teller
CNT	Carbon Nanotube
CVD	Chemical Vapor Deposition
DMF	Dimethylformamide
DW	Distilled Water
EPD	Electrophoretic Deposition
FTIR	Fourier Transform Infrared Spectroscopy
FTO	Fluorine-doped tin oxide
GNP	Graphene Nanoplatelet
ITO	Indium tin oxide
KBr	Potassium Bromide
UV-Vis	Ultraviolet-Visible

CHAPTER 1

INTRODUCTION

1.1 Research Background

Fiber-reinforced polymers (FRP) are in essence of a material that is composite which forms a polymer matrix combined with other reinforcing materials for instance fiber. In particular, the fibers are basalt, carbon, glass, and aramid, while asbestos, wood, and paper may also be used in certain situations. These days, FRP is flexible engineering materials used in various engineering fields despite their high particular strength-to-weight ratio, simple to mold different shapes through a one-step production process and less prone to corrosion, rendering them relatively low maintenance expenses compared to conventional metal for structural application (Hung et al., 2018). Due to extreme mechanical properties such as small value of density, the specific strength and modulus are high, low thermal expansion, and can tolerate with thermal expansion, FRP as structural materials has provided researchers the opportunity to create composite materials of high performance.

Besides, high surface carbon regions are current conductive materials as a conducting filler, for example, carbon nanofibers, graphene nanoplatelets (GNP), and carbon nanotubes (CNT). These nanoparticles' remarkable electrical and essential properties have made them allure for multi-uses in the automotive and aviation industries. Previous studies showed that GNPs often show better thermal stability and electrochemical behavior, along with properties of gas barriers. Diba et al. (2016) stated that controlled processing methods are important to utilize GNPs properties for the development of practical products. The usage of graphite nanoparticles as fillers to create nanocomposites of graphite–polymer has a cost-benefit as well as strong mechanical properties (Park et al., 2008).

The Electrophoretic Deposition (EPD) method in the manufacturing of advanced materials of ceramic and coatings has received the demand in educational and industrial sectors due to the great adaptability with various materials and their variations, and due to its cost-effectiveness involving basic apparatus as well. Besra and Liu (2007) stated that EPD was documented since 1808 when Russian scientist Ruess determined the motion in the water of clay particles caused by an electrical field. EPD is a desirable method for handling and deposition of nanomaterials in particular and especially for GNPs. EPD of coating has already achieved international recognition for aerospace, appliance, and general industrial coatings. High levels of automation, minimal pollution levels, high throw power, and homogeneity of the coating are the benefits that contributed to the use of EPD (Pierce, 1981). Other advantages are the advanced adherence of coatings that deposited electrophoretically and its higher density compared to dipped or sprayed coatings (Lamb & Reid, 1960).

Advanced FRPs are now used in aerospace engineering to produce several sections for structural products, such as fuselage frames, wings, tails, and door, as well as satellite and missile parts (Mangalgiri, 1999). Great mechanical and physical features are the prime specifications for advanced polymer fiber composites for aerospace applications. On the other side, Mangalgiri (1991) stated that for some time, massive all-composite aircraft were at the anvil. Those non-metallic products favorably compare with conventional metallic materials such as Al-Li, Al-Cu, Al-Zn, and Ti, new advanced alloys. The surface structures found useful in the aviation sector are focused on the fiber reinforcement is given in Table 1.1.

Table 1.1: FRP commonly used in aviation fields (Mangalgiri, 1999).

Fiber	Density (g/cc)	Modulus (GPa)	Strength (GPa)	Field area
Glass				
E-glass	2 to 55	65 to 75	2.2 to 2.6	Small parts of aircraft passenger, aircraft interiors.
S-glass	2 to 47	85 to 95	4.4 to 4.8	Greater loaded parts that place in passenger aircraft.
Aramid				
Low modulus	1 to 44	80 to 85	2.7 to 2.8	Bearing parts that are non-load.

Intermediate modulus	1 to 44	120 to 128	2.7 to 2.8	Casings motor of a rocket.
High modulus	1 to 48	160 to 170	2.3 to 2.4	Greater parts of loaded.
Carbon				
Standard modulus (high strength)	1.77 to 1.80	220 to 240	3.0 to 3.5	Almost all parts used in aircraft, satellites, and antenna dishes.
Intermediate modulus	1.77 to 1.81	270 to 300	5.4 to 5.7	Primary structural parts in high performance fighters.
High modulus	1.77 to 1.80	390 to 450	2.8 to 3.0 4.0 to 4.5	Structures of the space.
Ultra-high strength	1.80 to 1.82	290 to 310	7.0 to 7.5	Primary structural parts that put in high performance fighters.

1.2 Problem Statement

There are many new technologies where nanoparticles ought to be distributed into a polymer matrix. Such distributed particle structures are primarily used to improve the characteristics of the composite material. In addition, particles that agglomerate can minimize material efficiency by creating voids that serve as preferred locations for crack initiation and malfunction. Different methods are used to produce these fiber coatings, such as dip coating, spray coating, chemical vapor deposition, electrophoretic deposition, and so on. The method used to deposit GNPs in this study will be electrophoretic deposition (EPD). EPD has been found by previous researchers to be the best method because the EPD system has a limited period of formation, a convenient system, and the ability to produce uniform coatings. EPD also gives simple control over film thickness and morphology by easily changing depositing time and applied voltage. Previous researches have proved that nanofiller such as GNPs have improved compared to conventional composites in mechanical, electrical, thermal, and resistance (barrier) properties. Saba et al. (2014) stated that nanotechnologies are expected to have an impact and effect on the global economy of at least $3 trillion by 2020. However, nanotechnology-based industries, considering nanoparticles, are projected to need at least six million employees worldwide to support them by the end of the decade (Roco, Mirkin & Hersam, 2011).

In this study, the consequences of voltages set and time of deposition on GNPs dispersed in distilled water was determined to discover a homogenous deposit of the GNPs on the CF surfaces. GNPs are used as the filler because of their high surface area and it has been shown to enhance properties relative to unfilled polymer for polymer-GNP nanocomposites (Yang et al., 2010). Vandeperre and Biest (1999) stated that electrolysis happens at low voltages (almost 5V) and therefore gas bubbles at electrodes are possible at field strengths that are high enough to provide short deposition periods. According to the previous researches, high deposition voltage, short deposition time, and a short distance between electrodes may create more porous and thicker films. These have resulted in increased particle contact during migration while applying the electric field. In this scenario, the tendency of the particles to agglomerate during EPD is higher through looser packing, thicker and more porous coating. Therefore, it is important to make sure the EPD system is stable in appropriate voltage and deposition times to create homogenous deposition.

The EPD medium that is usually used to produce stable colloidal suspensions is organic and water-based EPD (Ervina et al., 2019). Stability of suspension is important as a stable suspension will not lead flocculation to happen and a thick adherent material deposits due to sedimentation at the bottom of the cell. However, too much stability disables EPD because to counteract the repulsive forces between particles, a strong electrical field is required (Aliofkhazraei & Makhlouf, 2016). On the other hand, water is much more friendly to the environment, but the electrolysis of water creates gas bubbles that undermine the deposited layer's performance. However, it has been reported that the use of low voltage in an aqueous EPD system could prevent the incorporation of bubbles (Besra et al., 2009; Besra et al., 2008).

The principle of axiomatic design, which is a widely used approach to optimizing design parameters, was used for the analytical design of EPD experiments. This method was suggested to improve the consistency of the deposition by applying mathematical and technical principles. As experimental approaches are often time-consuming and costly, the need to achieve the design objectives for the least number of experiments is a significant criterion.

1.3 Objectives

The purpose of this project is to evaluate the electrophoretic deposition (EPD) of graphene nanoplatelets (GNPs) dispersed in different solvents onto carbon fiber (CF) via axiomatic design concept.

The objectives of the project are as follows:

1. To evaluate the design of EPD parameters via axiomatic design concept.
2. To compare the stability of GNPs in the organic and non-organic solvents.
3. To determine the effect of applied voltages and deposition times on the deposition of GNPs onto CF fabric surface.

1.4 Summary of the Report

This project report consists of five chapters which are split by Introduction, Literature Review, Methodology, Results and Discussions, and Conclusion.

Chapter 1 describes the introduction of fiber-reinforced polymers (FRPs) and their applications in the engineering field. The nanoparticles that act as conducting filler and the methods of FRPs coating for example EPD system are also described in this chapter. This chapter also includes the problem statement and objectives. A problem statement was summarized to identify the research gap of the studies. The primary objectives of the study are carefully outlined in this chapter.

Chapter 2 reviews the literature on the recent progress made by previous researchers regarding the existing EPD systems and how it developed and worked with fiber-reinforced polymer and nanoparticles that are related to this project. The content in this chapter is organized accordingly into six subsections, such as fiber-reinforced polymer (FRP) composite, components of composite materials, properties of nanofillers, dispersion method, electrophoretic deposition process, and axiomatic design respectively.

Chapter 3 reports on the methodology of conceptual design, materials, sample preparation, and characterizations in the present study. This chapter is split into five subsections. The apparatus set up is also included in this chapter.

Chapter 4 reports the analysis design and expected outcome of the project related to the electrophoretic deposition (EPD) of graphene nanoplatelets (GNPs) dispersed in different solvents onto carbon fiber (CF) via axiomatic design concept. This chapter is organized into five subsections, such as axiomatic design concept, Brunauer-Emmet-Teller (BET) analysis, colloidal stability, Ultraviolet-Visible (UV-Vis) spectrophotometer, and surface morphology of GNP and deposited GNPs onto CF.

Chapter 5 presents the conclusion of the project. The summary is based on the chapters that have been written in this report. It evaluates the achievements of the present works as well as some suggestions for future work.

CHAPTER 2

LITERATURE REVIEW

2.1 Fiber Reinforced Polymer (FRP) Composite

Fibers that consist of high strength and elements that are embedded into matrix of distinct interfaces between them are known as Fiber-reinforced Polymer (FRP) composite materials. Fibers and matrix maintain their physical and chemical identities in this phase, and they establish a mixture of properties that cannot be accomplished by interacting individually with either of the constituents (Mallick, 2008). Given their generally high price, fiber-reinforced composite materials have gained attention for high-performance goods that need to be lightweight. Mallick (2008) stated that the most common form of use of fiber-reinforced composites in structural fields is called a laminate produced by piling and consolidating a combination of thin fiber layers and matrix into the specific thickness.

In recent decades, several researchers and scientists have attracted the attention of natural fibers because of their benefits over conventional glass and carbon fiber as an alternative to chemical composites. (Saheb & Jog, 1999). Natural fibers have multiple advantages over man-made glass and synthetic fibers, such as cheap, lower density, comparable basic strength properties, skin-free discomfort, reduced energy use, reduced health risk, renewability, recyclability and biodegradability (Malkapuram, Kumar, & Singh Negi, 2009). Nevertheless, the incompatibility of certain hydrophilic fibers and hydrophobic thermoplastic matrices with natural fibers or polymers is a certain restriction. Therefore, Malkapuram et al. (2009) stated that the fiber surface needs to be modified by using chemical modifications to enhance fiber-matrix adhesion.