EFFECT OF CARBON BLACK ON THE PROPERTIES OF GRAPHITE- EPOXY COMPOSITE FOR BIPOLAR PLATE

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This report is presented to fulfill part of the requirement for my Degree of Bachelor in Mechanical Engineering (Structure & Materials)

Faculty of Mechanical Engineering

Universiti Teknikal Malaysia Melaka

June 2013

SUPERVISOR DECLARATION

"I acknowledge that have read this thesis and in my opinion this thesis is sufficient in terms of scope and quality for the award of a Bachelor of Mechanical Engineering (Structure & Materials)"

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Supervisor Name: DR MOHD ZULKEFLI BIN SELAMAT

DATE: 28th JUNE 2013

DECLARATION

"I hereby declare that this report is my only own work except for the summaries and article that each of that I already cited in the references"

Signature: _____

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Date: 28th JUNE 2013

ACKNOWLEDGEMENT

In the name of Allah, the most gracious, the most merciful, all the praises and thank be to Allah swt for giving me strength to completely finish my final year project successfully. I like to give special thanks to the people who, one way or another had shared in my activities that is my supervisor Dr Mohd Zulkefli bin Selamat. May Allah swt bless him in this world and hereafter.

Also I like to express my gratitude to Universiti Teknikal Malaysia Melaka for providing a place for me to conduct my project entitiled “Effect of Carbon Black on the Properties of Graphite-Epoxy Composite for Bipolar Plate”.

Not to forget all of the Faculty of Mechanical Engineering’s staff members for guiding and rendered their help during the period of my project work.

Lastly, my special thank be to my lovely parents for their moral support and encouragement and also for my classmate who always give a help to me whenever I need it the most.

ABSTRACT

The performance of polymer exchange membrane fuel cell (PEMFC) is depends to the bipolar plate. In this research, the alternatives material for bipolar plate that is graphite-epoxy composite has been study. Different ratio of graphite (G) and carbon black (CB) polymer exchange membrane fuel cell has been mixed with epoxy to fabricate the conductive composite bipolar plate. The composition of fillers: binder is fixed 80:20 and the percentage of CB has been varying from 5% up to 30% from total percentage of fillers. The material will be pre-mixing in the ball mill machine. The conductive composite will be fabricated by using hot compressing molding. Properties of the bipolar plate such as electrical conductivity, flexural strength, hardness and density will be measured. The result from the tests will be analyzed whether the properties of conductive composite were achieved and meted the DOE requirement. From the experiment that has been conducted, the critical loading of CB content in the composite is 20% and the present of carbon black in the composite improved the properties of graphite- epoxy composite such as electrical conductivity, flexural strength, density and hardness.

ABSTRAK

Keupayaan polimer pertukaran membran sel bahan api adalah bergantung kepada dwikutub plat. Dalam kajian ini, bahan yang akan digunakan adalah komposit grafit epoksi. Pelbagai nisbah grafit dan juga karbon hitam dicampur dengan epoxy untuk menghasilkan plat dwikutub komposit yang bersifat konduktif. Bahan- bahan tersebut akan dilakukan pra-campuran menggunakan mesin ball mill. Plat dwikutub akan dihasilkan menggunakan mesin tekanan bersuhu tinggi. Ciri- ciri yang terdapat pada plat dwikutub seperti pengaliran elektrik, kekuatan lenturan, kekerasan dan juga ketumpatan akan diukur dan hasil daripada kajian yang dilakukan akan di analisa dan dibandingkan dengan ciri- ciri plat dwikutub samada mencapai kriteria yang telah ditetapkan oleh Jabatan Tenaga. Berdasarkan kajian yang dilakukan, kandungan maksimum karbon hitam adalah 20% dan kehadiran karbon hitam telah meningkatkan ciri- ciri yang terdapat dalam komposit grafit epoksi seperti pengaliran elektrik, kekuatan lenturan, kekerasan dan juga ketumpatan.

TABLE OF CONTENT

LIST OF TABLES

LIST OF FIGURES

FIGURES **TITLE** **PAGES**

CHAPTER 1

INTRODUCTION

1.1 Overview

Fuel cells are being examined by many researchers as a new power source to solve the exhaustion of fossil fuel and global warming. Among the fuel cell systems available, the Proton exchange membrane fuel cell (PEMFC) is expected to replace the internal combustion engine in transportation applications due to its fast start-up and response time, low operating temperature and high power density. In PEM fuel cell systems, bipolar plate are one of the major parts that have function with an electrical connection between the electrodes, separation of reactant gases and a pathway for residual water in the cell stack.

The main process involved in PEM fuel cell is as stated below.

i. Pure hydrogen is passed through the flow plates in the anode (negative) on one side of the fuel cell, and oxygen from the air passed through to the cathode (positive) on the other side of the fuel cell.
ii. The anode is coated with a platinum catalyst which enables the hydrogen to split into positive hydrogen ions (protons) and negatively charged electron.
iii. The PEM allows only the protons to pass through the cathode. The electrons must then travel along an external circuit to the cathode producing an electrical current.
iv. At the cathode, the electrons and protons from the hydrogen combine with the oxygen to form water. The water then leaves the cell. This is a continuous process so long as hydrogen and oxygen is supplied.

But, the main concern in this research is the bipolar plate itself. Bipolar plate acts as the backbone of a hydrogen fuel cell power stack. To commercialize fuel cell, bipolar plate needs to be fabricated in mass production and made of material with excellent flexural strength, better electrical conductivity and low in mass density.

1.2 Objectives

The main objectives of this research is to study the effect of Carbon Black on the properties of Graphite / Epoxy composite and to determine the critical loading of Carbon Black in Graphite / Carbon Black / Epoxy composite.

1.3 Problem statement

Fuel cell converts chemical energy to electrical energy with high efficiency and low emission of pollutants. Bipolar plate is one of the most significant parts in fuel cells, which constitutes the backbones of a fuel cell stack, conducts current between cells, facilitates water and thermal management, and provides conduits for conduits reactant gases. Generally, there are two types of bipolar plate in PEMFCs that are metal-based bipolar plates and pure graphite bipolar plates. Metallic materials have advantages over pure graphite because of their higher mechanical strength and better electrical conductivity. However, corrosion resistance is a major concern that remains to be solved as metals may develop oxide layers that increase electrical resistivity, thus lowering the fuel cell efficiency. The metal-based bipolar plates are such as stainless steel, aluminum, nickel, copper, titanium, bulk amorphous alloys and carbon steels. The metal-based bipolar plates have higher mechanical strength, low gas permeability and much superior manufacturability. However, the main handicap of the metal-based bipolar plate is the lack of ability to combat corrosion in the harsh acidic and humid environment in PEMFCs and considerable power degradation that may be caused by metal ions. Meanwhile, for the pure graphite, it is very expensive and involves a huge amount of money to fabricate it plus it is very brittle. So, to overcome this problem, the bipolar plate which is known as conducting polymer composite which is made from two different materials will be invented. Filler is one of the main materials which influence the electrical properties of bipolar plate. Multifiller is preferredable compare to single filler due to its better electrical conductivity. In this project, graphite and carbon black will be used as filler and epoxy will be used as a material for binder. Epoxy as well, has higher melting point that enable it to withstand higher temperature before going to melt. Plus, epoxy is in the liquid form that make it is easier to mix it up with the filler for the process purpose. There is no need to use heat to mix up the two materials. Because of its thermal resistance, epoxy is suitable to be fabricating as bipolar plate.

1.4 Scope

This research will study the effect of Carbon Black loading on the electrical and mechanical properties of Graphite / Carbon Black / Epoxy composite. The critical loading of Carbon Black in Graphite / Epoxy composite needs to be determined in order to get the maximum weight percentage of carbon black in the conducting polymer composite. The ratio of carbon black will be vary from 5 wt% to 25 wt% from the 80% of filler content while for the binder that is epoxy will be 20% for all specimens. Before the formation of the composite that are using hot press machine to compress it, the main filler and second filler will be mixed using ball mill. The critical loading of Carbon Black in Graphite/Epoxy composite needs to be determined and to be used as composition of Graphite/Carbon Black/Epoxy composite for bipolar plate

CHAPTER 2

LITERATURE REVIEW

2.1 Overview of literature review

This chapter will present the review of bipolar plate in a fuel stack. The review is from the recent and past journals, technical papers and reference books have been studied to understand the related topic area of this project. Plus, this chapter will go through deeply regarding bipolar plate such as its background, fabrication and about the testing used in order to know the properties of the bipolar plate.

2.2 Bipolar plate

Bipolar plate has several types such as metal based, carbon based and conducting polymer composite. According to E. Plane (2012), the bipolar plate contributes the majority of the weight and cost of PEM fuel cell stack which about 80% of the total weight and 30 to 40 % of cost. Therefore, bipolar plate with lighter weight, smaller volume and low cost need to be fabricate proportionally with low hydrogen permeability, high electrical and mechanical conductivity and mechanical robustness. Figure 2.1 shows the stack of a PEMFC consisting various component such as bipolar plate, end plate, membrane electrode assembly (MEA) and gas diffusion layer (GDL).

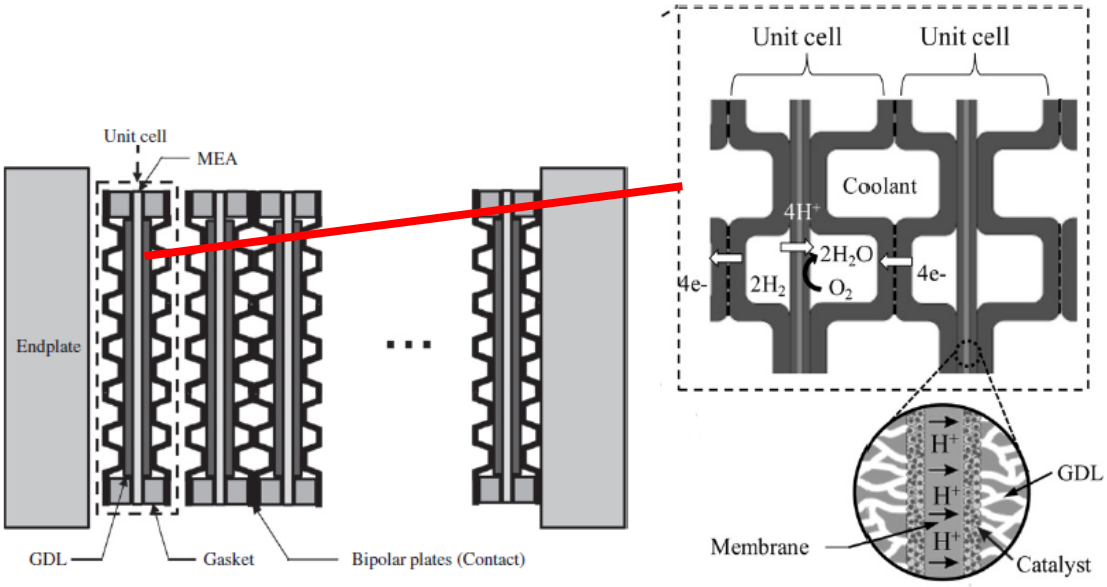

Figure 2.1: Schematic drawing of the PEMFC

(Source: Ha Na Yu (2011) and Jun Woo (2013))

2.2.1 Bipolar requirement

Bipolar plate is the main component in PEMFC. This electrochemical device will be malfunction if the bipolar plate is not functioning well. For the successful design of bipolar plate, there are some properties that need to be considered such as mechanical strength, electrical and thermal conductivities, gas permeability, corrosion resistance and low density. Some standards have been fixed by US Department of Energy (DOE) regarding the property of bipolar plate. These can be seen on the table shown below.

Table 2.1: Required properties for the bipolar plate.

Property	Value
Electrical conductivity	>100 S/cm
Weight	<0.4 kg/kW
Flexural strength	>25 MPa
Flexibility	3-5 deflection at mid-span
Thermal conductivity	>10 W/(mk)
Gas permeability	$<2\times 10^{-6} cm^3 cm^{-2} s^{-1}$ at 80 ℃
Corrosion resistance	$<1\ \mu A\ cm^{-2}$

(Source: The office of Energy Efficient and Renewable Energy (2010))

2.2.2 Function of bipolar plate

Bipolar plate has several functions within the fuel cell stack. The crucial function of bipolar plate according to E. Planes (2012) are homogeneously distribute gases over the area of the cell, separate the fuel and oxidant gases and prevent gas leakage, collect the current produced in the electrochemical reactions, discharge the water produced and ensure the mechanical strength of the stack.

2.2.3 Basic principles of PEM Fuel cells

As stated before this, bipolar plate has many functions that make it become multi-functional component in a PEMFC stack. Bipolar plate also provides the electrical connection from cell-to-cell and it separates the reactive gases. Hwang et al. in his journal dated 2008 states that at the anode side of the plate, hydrogen gas is consumed to produce electrons and protons as follows,

$$2H_2 \rightarrow 4H^+ + 4e^-$$

Oxidation process of hydrogen will occur at the anode when the electrons are collected at the anode and the protons enter the electrolyte. Otherwise, reduction process of oxygen will occur at the cathode due to oxygen gas combines with electrons from the cathode and protons from the electrolyte to produce water.

$$O_2 + 4H^+ + 4e^- \rightarrow 2H_2O$$

2.2 4 Filler on bipolar plate

The performance of bipolar plate is depends on its filler. In order to get higher electrical and thermal conductivities of the composites, the filler must be filled with high loadings of conductive particle such as carbon black or graphite.

2.2.5 Types of bipolar plate material

Recently, there are many research have been done regarding materials and methods to fabricate bipolar plate in such way so that the performance of bipolar plate will be at maximum level. Bipolar plate consists of several types that are metallic bipolar plate and graphitic bipolar plate.

2.2.5.1 Metallic Bipolar Plate

The use of metal bipolar plate in PEMFC stacks offers a number of advantages especially in machining it like stamping, low-cost mass production, non porous which means it can be fabricated to a very thin film (<200μm) and at the same time can reduced weight and volume in the overall stack, impermeability to fuel, oxidant and water vapor.

But, metallic bipolar plate also has its disadvantages. According to Shahram Karimi et al. (2012), bipolar plate is more susceptible to corrosion which can adversely affect their performance and durability. The corrosion can take place both at anode and cathode of an operating PEMFC. Research by Cheng et al. (2007) showed corrosion of

the bipolar plate leads to a release of metal ions that can contaminate the electrolyte membrane and poison the electrode catalysts.

In order to avoid corrosion on the bipolar plate, the bipolar plate is coated with protective coating layers. The coating is conductive and adheres to the base metal without exposing the substrate to corrosive media. There are two types of coatings; that are carbon-based such as graphite, conductive polymer, diamond-like carbon and metal-based such as noble metals, metal nitrides and metal carbides. Noble metals such as gold and platinum is very minimal in its usage because of it is very costing even as thin coatings.

2.2.5.2 Polymer Composite Bipolar Plate

Polymer composites is a combination of graphite or carbon filler and a polymer resin either thermoplastic of thermoset matrices with conventional polymer processing methods such as compression molding and injection molding. Lower cost, lightweight, easily machined, good corrosion resistance, good mechanical properties and good gas tightness are the major advantages of this bipolar plate. Unfortunately, this polymer composite bipolar plate is very low in its electrical conductivity. So it needs excessive conductive fillers to be incorporated with. In this case, must bear in minds that it is very difficult to get high conductivity and excellent mechanical properties simultaneously.