



**Faculty of Mechanical Engineering**

**HIGH ELECTRICAL CONDUCTIVITY BIPOLAR PLATE USING  
STANNUM/GRAPHITE POLYMER COMPOSITE**

**Farhana binti Masron**

**Master of Science in Mechanical Engineering**

**2018**

**HIGH ELECTRICAL CONDUCTIVITY BIPOLAR PLATE USING  
STANNUM/GRAPHITE POLYMER COMPOSITE**

**FARHANA BINTI MASRON**

**A thesis submitted  
in fulfilment of the requirements for the degree of Master of Science  
in Mechanical Engineering**

**Faculty of Mechanical Engineering**

**UNIVERSITI TEKNIKAL MALAYSIA MELAKA**

**2018**

## DECLARATION

I hereby declare that this thesis entitled “High Electrical Conductivity Bipolar Plate Using Stannum/Graphite Polymer Composite ” is the result of my own research except as cited in the references. The thesis has not been accepted for any degree and is not concurrently submitted in candidature of any other degree.

Signature : .....

Name : ..... FARHANA BINTI MASRON .....

Date : .....

## **APPROVAL**

I hereby declare that I have read this thesis and in my opinion, this thesis is sufficient in terms of scope and quality for the award of Master of Science in Mechanical Engineering.

Signature : .....

Supervisor name : ASSOC. PROF. DR. MOHD ZULKEFLI BIN SELAMAT

Date : .....

## **DEDICATION**

I dedicate this dissertation to my husband, Hamzaitul Akmarizal bin Hamdan. My gratitude for your patience, encouragement and understanding. He is always there to cheer me up when I was discouraged, wiped my tears away when I faced difficulties.

To my beloved parents, Masron b. Ahmad Dasuki and Habsah bt. Surip, my deepest gratitude for instilling the importance of higher education in me. Their love has encourage me to build a happy and successful life in the world and also in Paradise. InsyaAllah!

## ABSTRACT

Nowadays, transportation is one of the promising sector for Proton Polymer Membrane Fuel Cell (PEMFC) due to the possibility of zero pollution and environment friendly vehicles and also the future expect of fossil fuels depletion . The fabrication methods of this composite and composition ratios have significant effects on its electrical and mechanical properties. This research was focused on to Graphite (G) and Stannum (Sn) as conductive fillers and Polypropylene (PP) polymer as binder. Firstly, all materials will be dry mixed using a ball mill machine with several ratios of composition. The shape of this composite was mould with the dimensions of  $140 \times 60 \times 3$  mm through the compression machine to form a bipolar plate. There were two types of composition that had been fabricated which were G/Sn and G/Sn/PP composites. Meanwhile, for G/Sn composites, two methods were applied which were sintering and compression moulding methods. For sintering method, the weight percentage of the secondary filler (Sn) is increased from 20 wt.% to 40 wt.% of the total weight percentage of fillers. Meanwhile, for G/Sn/PP, the ratio of conductive fillers and binder has been fixed at 80:20 and the ratio of conductive fillers between first and secondary filler has been varied, for G (60 to 70 wt.%) and Sn (10 to 20 wt.%). Two different types of PP polymer in powder form were used which were Low Density Polypropylene (LD-PP) and High Density Polypropylene (HD-PP). The effect of different filler material loadings on G/PP and G/Sn/PP composites properties such as electrical conductivity, bulk density, hardness and gas permeability were tested, observed and confirmed that they are able to meet the United State Department of Energy ( U.S. DOE) target properties as PEMFC bipolar plate. Results showed G/Sn produced using hot compression moulded with Sn loading of 20 wt.% of Sn loading obtained the highest electrical conductivity of 889.64 S/cm. Although the usage of the hot compression moulding method increased the value of bulk density, all results still met the U.S. DOE target which is it must be lower than  $1.9 \text{ g/cm}^3$ . Other than that, hardness value for compression moulding method showed improvement compared to the sintering process method. Even though G/Sn composites for compression moulding method perform better results compared to sintered method, these composites did not exhibit good mechanical properties and showed the brittleness characteristic. These composites were also brittle. In order to overcome this weakness, PP polymer was added in G/Sn composites and the effects of PP types, Sn loading and hot compression moulding temperatures in G/Sn/PP (LD-PP and HD-PP) composites on electrical and mechanical properties were determined. Based on the results obtained, G/Sn/HD-PP composites have shown better electrical and mechanical properties as compared to G/Sn/LD-PP composites. Meanwhile, for moulding temperature for LD-PP and HD-PP were  $170^\circ\text{C}$  and  $175^\circ\text{C}$  respectively. Lastly, the optimum weight ratio of G/Sn/PP (LD-PP and HD-PP) composites was 15 wt.% of Sn loading due to high electrical conductivity, good bulk density and shore hardness value.

## ABSTRAK

Pada masa kini, pengangkutan merupakan salah satu sektor yang menjanjikan peluang yang baik untuk Sistem Polimer Elektrolit Membran Sel Fuel (PEMFC) disebabkan oleh penghasilan kenderaan mesra alam sekitar dan sifar pencemaran serta pengurangan bahan api fosil pada masa hadapan. Kaedah fabrikasi, nisbah dan komposisi komposit mempunyai kesan yang besar ke atas sifat-sifat elektrik dan mekanikal. Kajian ini, tumpuan diberikan kepada Grafit (G) dan Stanum (Sn) sebagai pengisi konduktif dan polimer Polipropelena (PP) sebagai pengikat. Pertama, semua bahan-bahan akan dicampurkan menggunakan mesin pengisar bebola dengan beberapa nisbah komposisi. Komposit ini telah dibentuk menggunakan acuan dengan dimensi  $140 \times 60 \times 3$  mm melalui mesin mampatan untuk membentuk plat dwikutub. Terdapat dua jenis komposit yang telah direka iaitu komposit G / Sn dan komposit G / Sn / PP. Bagi komposit G / Sn, dua kaedah telah digunakan iaitu kaedah pensinteran dan kaedah pengacuan mampatan. Untuk kaedah pensinteran, peratusan berat untuk pengisi kedua (Sn) dinaikkan daripada 20 wt.% sehingga 40 wt.% daripada jumlah peratusan berat pengisi. Sementara itu, bagi G/Sn/PP, nisbah pengisi konduktif dan pengikat telah ditetapkan 80:20 dan nisbah pengisi konduktif antara pengisi pertama dan kedua adalah berbeza-beza, G (60 sehingga 70 wt.%) dan Sn (10 sehingga 20 wt.%). Dua jenis polimer PP dalam bentuk serbuk telah digunakan iaitu Polipropelena Ketumpatan Rendah (LD-PP) dan Polipropelena Ketumpatan Tinggi (HD-PP). Kesan daripada perbezaan nisbah bahan pengisi di G/PP dan G/Sn/PP komposit seperti sifat kekonduksian elektrik, kekuatan lenturan, ketumpatan pukal, kekerasan dan kebolehtelapan gas telah diuji, dipatuhi dan mengesahkan mereka dapat memenuhi sasaran Jabatan Tenaga Amerika (U.S. DOE) sebagai plat dwikutub PEMFC. Keputusan menunjukkan komposit G/Sn mempunyai kekonduksian elektrik untuk kaedah acuan mampatan, komposit yang bernisbah Sn 20 wt.% menunjukkan kekonduksian elektrik yang tertinggi dengan 889.64 S/cm. Walaupun dengan menggunakan kaedah pengacuan mampatan telah meningkat nilai ketumpatan pukal, semua keputusan masih memenuhi sasaran U.S. DOE iaitu kurang daripada  $1.9 \text{ g/cm}^3$ . Selain daripada itu, nilai kekerasan “shore” untuk kaedah pengacuan mampatan menunjukkan peningkatan berbanding kaedah proses pensinteran. Walaupun komposit G/Sn untuk kaedah pengacuan mampatan menunjukkan keputusan yang lebih baik berbanding kaedah persinteran, komposit ini tidak mempamerkan sifat mekanikal yang baik seperti kekuatan dan ia juga agak rapuh. Untuk mengatasi kelemahan ini, polimer PP telah ditambah dalam komposit G / Sn dan kesan terhadap jenis PP, nisbah Sn dan suhu pengacuan mampatan dalam G / Sn / PP (LD-PP dan HD-PP) komposit pada sifat-sifat elektrik dan mekanikal telah dikenalpasti. Berdasarkan keputusan yang diperolehi, komposit G / Sn / HD-PP telah menunjukkan sifat-sifat elektrik dan mekanikal yang lebih baik berbanding dengan komposit G / Sn / LD-PP. Sementara itu, bagi suhu membentuk untuk LD-PP adalah  $170^\circ\text{C}$  manakala bagi HD-PP adalah  $175^\circ\text{C}$ . Akhir sekali, nisbah berat optimum bagi G / Sn / PP (LD-PP dan HD-PP) komposit adalah 15 wt.% nisbah berat Sn disebabkan kekonduksian elektrik yang tinggi, ketumpatan pukal dan nilai kekuatan yang baik.

## **ACKNOWLEDGEMENTS**

First and foremost, In the name of Allah, I am thankful to Allah, The Al Mighty, for the blessings that has made this journey successful

I would like to take this opportunity to express my sincere acknowledgement to my supervisor, Assoc. Prof. Dr. Mohd. Zulkefli bin Selamat from the Faculty of Mechanical Engineering, Universiti Teknikal Malaysia Melaka (UTeM) for his essential supervision, support, encouragement, experiences and knowledge that has helped me towards the completion of this thesis.

I would also like to thank to all lecturers and staff of the Faculty of Mechanical Engineering that were involved directly or indirectly for all their assistance throughout in this project.

I am also obliged to everyone who were directly and indirectly involved in contributing the ideas. Millions of appreciation to my beloved family for their moral and material support. My gratitude also goes out to all my friends for their support and constructive critics. With the support and love given by all of you, I hope I will become a successful person and can contribute to my beloved country, Malaysia.

Thank you.



## TABLE OF CONTENTS

	<b>PAGE</b>
<b>DECLARATION</b>	
<b>APPROVAL</b>	
<b>DEDICATION</b>	
<b>ABSTRACT</b>	<b>i</b>
<b>ABSTRAK</b>	<b>ii</b>
<b>ACKNOWLEDGEMENTS</b>	<b>iii</b>
<b>TABLE OF CONTENTS</b>	<b>iv</b>
<b>LIST OF TABLES</b>	<b>viii</b>
<b>LIST OF FIGURES</b>	<b>xi</b>
<b>LIST OF APPENDICES</b>	<b>xv</b>
<b>LIST OF ABBREVIATIONS</b>	<b>xvi</b>
<b>LIST OF SYMBOLS</b>	<b>xviii</b>
<b>LIST OF PUBLICATIONS</b>	<b>xix</b>
<b>CHAPTER</b>	
<b>1. INTRODUCTION</b>	<b>1</b>
1.1 Background	1
1.2 Problem Statement	6
1.3 Objectives	8
1.4 Scope	8
1.5 Thesis Layout	9
<b>2. LITERATURE REVIEW</b>	<b>10</b>
2.1 Introduction	10
2.2 Fuel Cells	11
2.3 Operation of PEMFC	13
2.4 Components of PEMFC	14
2.4.1 Membrane-Electrode Assembly (MEA)	15
2.4.2 Bipolar Plate	16
2.5 Bipolar Plate Materials	17
2.5.1 Graphite Bipolar Plate	19

2.5.2	Metallic Bipolar Plate	20
2.5.3	Polymer Composite Bipolar Plate	22
2.6	Conflict Issues in Polymer Composite Bipolar Plate	24
2.7	Manufacturing Process of Bipolar Plates	24
2.7.1	Sintering Process	25
2.7.2	Hot Compression Moulding Process	27
2.7.3	Injection Moulding Process	28
2.8	Conductive Polymer Composites	29
2.8.1	Percolation Theory	31
2.9	Recent Developments on Composite Bipolar Plate	34
2.10	Summary	40
<b>3.</b>	<b>METHODOLOGY</b>	<b>42</b>
3.1	Experimental Overview	42
3.2	Materials Selection	44
3.2.1	Graphite	45
3.2.2	Stannum	46
3.2.3	Polypropylene Polymer	47
3.3	Processing Method	49
3.3.1	Pulverizing of PP	50
3.3.2	Composition Ratio	51
3.3.3	Pre-Mixing Process	52
3.4	Types of Fabrication Method	53
3.4.1	Sintering Process	54
3.4.2	Hot Compression Moulding Process	56
3.5	Cutting Process	57
3.6	Testing Characterization	58
3.6.1	Electrical Conductivity Measurement	58
3.6.2	Flexural Test	59
3.6.3	Bulk Density Test	61
3.6.4	Shore Hardness Test	62
3.6.5	Gas Permeability Test	63
3.6.6	Microscopic Analysis and EDX	64

<b>4.</b>	<b>RESULT AND DISCUSSION</b>	<b>66</b>
4.1	G/Sn Composites Through Sintering Method	66
4.1.1	Effect of Sintering Temperature on Electrical Conductivity	67
4.1.2	Effect of Sintering Time on Electrical Conductivity	67
4.1.3	Properties of Sintered G/Sn Composite	68
4.1.4	Gas Permeability Properties	70
4.1.5	Microscopic Analysis and EDX	71
4.2	G/Sn Composites Through Hot Compression Moulding Method	78
4.2.1	Effect of Moulding Temperature on Electrical Conductivity	78
4.2.2	Effect of Hot Compression Load on Electrical Conductivity	79
4.2.3	Effect of Hot Compression Time on Electrical Conductivity	80
4.2.4	Properties of G/Sn Composites	81
4.2.5	Gas Permeability Properties	83
4.2.6	Microscopic Analysis	84
4.3	Comparison between G/Sn Composites through Sintering and Hot Compression Moulding Methods	87
4.3.1	Electrical Conductivity	87
4.3.2	Bulk Density	89
4.3.3	Shore Hardness	90
4.3.4	Summary of Findings	91
4.4	The Effect of Sn on the G/Sn/LD-PP Composite	92
4.4.1	Electrical Conductivity	93
4.4.2	Flexural Strength	94
4.4.3	Bulk Density	96
4.4.4	Shore Hardness	97
4.4.5	Gas Permeability Properties	98
4.4.6	Microscopic Analysis and EDX	98
4.4.7	Summary of Findings	106
4.5	The Effect of Sn on the G/Sn/HD-PP Composite	108
4.5.1	Electrical Conductivity	108
4.5.2	Flexural Strength	109
4.5.3	Bulk Density	110
4.5.4	Shore Hardness	111

4.5.5	Gas Permeability Properties	112
4.5.6	Microscopic Analysis	113
4.5.7	Summary of Findings	118
4.6	Comparison between LD-PP and HD-PP on G/Sn/PP Composites	120
4.6.1	Electrical Conductivity	120
4.6.2	Flexural Strength	121
4.6.3	Bulk Density	122
4.6.4	Shore Hardness	123
4.6.5	Summary of Findings	124
4.7	Comparison between Sintered, Hot Compression G/Sn Composites and Hot Compression G/Sn/PP Composites	126
<b>5.</b>	<b>CONCLUSION AND RECOMMENDATION</b>	<b>129</b>
5.1	Conclusion	129
5.2	Recommendation	131
	<b>REFERENCES</b>	<b>132</b>
	<b>APPENDICES</b>	<b>145</b>

## LIST OF TABLES

<b>TABLE</b>	<b>TITLE</b>	<b>PAGE</b>
2.1	Difference in fuel cells.	12
2.2	Components of MEA and their functions.	16
2.3	U.S. DOE requirements for PEMFC bipolar plate.	18
2.4	Properties of G bipolar plate.	19
2.5	Properties of SS, Al and Ti bipolar plate.	21
2.6	Comparisons between sintering, hot compression moulding and injection moulding processes.	29
2.7	Electrical conductivity of polymers, conductive carbon fillers and metals.	30
2.8	Compression moulding parameters of G/Sn composite bipolar plate.	36
2.9	Electrical conductivity and bulk density for G/Sn composite at 80/20 weight ratio.	37
2.10	Compression moulding parameters of G/Sn/LD-PP.	37
2.11	Results for electrical conductivity and mechanical properties.	38
2.12	Compression moulding parameters of G/Sn/LD-PP.	39
2.13	Results for electrical conductivity and mechanical properties.	40
3.1	Properties of G, Sn and PP (LD-PP and HD-PP).	44
3.2	Mechanical properties of G.	46
3.3	Mechanical properties of Sn.	47
3.4	Mechanical properties of PP polymer.	49

3.5	Composition of G and Sn for G/Sn composites.	51
3.6	Composition of G, Sn and PP for G/Sn/LD-PP composite.	52
4.1	Electrical conductivity for 300°C to 450°C of sintering temperatures.	67
4.2	Electrical conductivity for two to five hours of sintering time.	68
4.3	Parameters during sintering process for sintered G/Sn composite.	68
4.4	Electrical conductivity of sintered G/Sn composites.	69
4.5	Bulk density of sintered G/Sn composites.	69
4.6	Shore hardness of sintered G/Sn composites.	70
4.7	Results of gas permeability test for sintered G/Sn 20 wt.% composite.	70
4.8	Electrical conductivity of G/Sn 20 wt.% at different moulding temperatures.	78
4.9	Electrical conductivity of G/Sn 20 wt.% at different compression loads.	79
4.10	Electrical conductivity of G/Sn 20 wt.% at different compression time.	80
4.11	Formation parameters of hot compression moulded G/Sn composite.	81
4.12	Electrical conductivity of hot compression moulded G/Sn composites.	82
4.13	Bulk density of hot compression moulded G/Sn composites.	82
4.14	Shore hardness of hot compression moulded G/Sn composites.	83
4.15	Results of gas permeability test for G/Sn 20 wt.% composite.	83
4.16	Summary finding of electrical and mechanical properties of G/Sn composites as compared to U.S. DOE target.	92
4.17	Gauge pressure readings of gas permeability G/Sn/LD-PP composite.	98
4.18	Summary finding of the best electrical and mechanical properties results of G/Sn/LD-PP composites as compared to U.S. DOE target.	107
4.19	Gauge pressure readings of gas permeability G/Sn/PP composite (LD and HD-PP).	113

4.20	Summary finding of electrical and mechanical properties of G/Sn/HD-PP composites as compared to U.S. DOE target.	119
4.21	Summary finding of electrical and mechanical properties of G/Sn/PP composites as compared to U.S. DOE target.	125
4.22	Summary finding of electrical and mechanical properties of sintered G/Sn composite, hot compression moulded G/Sn composite, G/Sn/LD-PP and G/Sn/HD-PP as compared to U.S. DOE target.	128

## LIST OF FIGURES

FIGURE	TITLE	PAGE
1.1	Schematic diagram of electrochemical conversion process for typical fuel cell.	3
2.1	Schematics process of PEMFC.	13
2.2	Expanded view of PEMFC stack.	15
2.3	Schematic illustration of sintering particles : a) particles in contact, b) formation of neck, grain boundaries and pore, c) final sintered geometry.	25
2.4	Graph of temperature against time for sintering process.	26
2.5	Percolation pathway schematics.	31
2.6	Percolation theory S-curve.	32
2.7	Volume Fraction versus conductivity.	33
2.8	Relative cost and weight components of PEMFC stack using G bipolar plate.	34
3.1	Flow chart of fabrication method in this research.	43
3.2	Atom bonding of G particle.	45
3.3	Powder type of Sn.	46
3.4	Monomer of propylene become polypropylene after polymerization.	48
3.5	Machine used in pulverising of PP (a) Pulverizer machine (b) Sieve shaker machine.	50
3.6	Ball mill machine.	53
3.7	Sample for sintering process.	54



3.8	200 Tonne High Speed Hot Compression Moulding Machine.	55
3.9	KSL 1700 High Temperature Muffle Furnace.	55
3.10	Sample of composites.	56
3.11	Proxxon Table Saw.	57
3.12	Jandel Multiheight Microposition Probe.	59
3.13	INSTRON 5855 Universal Testing Machine.	60
3.14	Flexural specimens during test.	60
3.15	Electronic densimeter.	61
3.16	Illustration of electronic densimeter used.	62
3.17	Shore D durometer.	63
3.18	Illustration of gas permeability test apparatus.	64
3.19	SEM-EDX machine.	64
4.1	SEM image of sintered G/Sn 40 wt.% composite.	71
4.2	SEM image of sintered G/Sn composites.	73
4.3	SEM-EDX result for sintered G/Sn composite at point Spectrum 2.	75
4.4	SEM-EDX result for sintered G/Sn composite at point Spectrum 3.	76
4.5	SEM-EDX result for sintered G/Sn composite at point Spectrum 4.	77
4.6	SEM image of hot compression moulded G/Sn 40 wt.% composite.	84
4.7	SEM image of hot compression moulded G/Sn composites for 20 wt.%, 30 wt.% and 40 wt.% of Sn.	85
4.8	The electrical conductivity of sintering and hot compression moulded G/Sn composites.	88
4.9	The bulk density of sintered and hot compression moulded G/Sn composites.	89
4.10	The shore hardness of sintered and hot compression moulded G/Sn composites.	90

4.11	The electrical conductivity for 10, 15 and 20 wt.% of Sn loading at 170, 175 and 180°C of compression moulding temperatures respectively.	93
4.12	The flexural strength for 10, 15 and 20 wt.% of Sn at 170, 175 and 180°C of moulding temperatures.	95
4.13	The bulk density for 10, 15 and 20 wt.% of Sn loading at 170, 175 and 180°C of moulding temperatures.	96
4.14	The shore hardness for 10, 15 and 20 wt.% of Sn at 170, 175 and 180°C of moulding temperatures.	97
4.15	SEM image of G/Sn/LD-PP 10 wt.% composite at 175°C of moulding temperature.	99
4.16	SEM image of G/Sn/LD-PP 20 wt.% composite at 175°C of moulding temperature.	99
4.17	SEM image of G/Sn/LD-PP 15 wt.% composite at 170°C of moulding temperature.	101
4.18	SEM image of G/Sn/LD-PP 15 wt.% composite at 180°C of moulding temperature.	101
4.19	SEM images of G/Sn/LD-PP composites.	102
4.20	SEM-EDX result for G/Sn/LD-PP 10 wt.% composite at 170°C moulding temperature at point Spectrum 1.	103
4.21	SEM-EDX result for G/Sn/LD-PP 10 wt.% composite at 170°C moulding temperature at point Spectrum 2.	104
4.22	SEM-EDX result for G/Sn/LD-PP 10 wt.% composite at 170°C moulding temperature at point Spectrum 3.	105
4.23	The electrical conductivity (S/cm) for 10, 15 and 20 wt.% of Sn loading at 170, 175 and 180°C of moulding temperatures.	108

4.24	The flexural strength for 10, 15 and 20 wt.% of Sn loading at 170, 175 and 180°C of moulding temperatures.	110
4.25	The bulk density for 10, 15 and 20 wt% of Sn loading at 170, 175 and 180°C of moulding temperatures.	111
4.26	The shore hardness for 10, 15 and 20 wt.% of Sn loading at 170, 175 and 180°C of moulding temperatures.	112
4.27	SEM image of G/Sn/HD-PP 10 wt.% composite at 175°C of moulding temperature.	114
4.28	SEM image of G/Sn/HD-PP 20 wt.% composite at 175°C of moulding temperature.	114
4.29	SEM image of G/Sn/HD-PP 15 wt.% composite at 170°C of moulding temperature.	116
4.30	SEM image of G/Sn/HD-PP 15 wt.% composite at 180°C of moulding temperature.	116
4.31	SEM images of G/Sn/HD-PP composites.	117
4.32	Electrical conductivity for LD-PP and HD-PP of G/Sn/PP composites.	120
4.33	Flexural strength for LD-PP and HD-PP of G/Sn/PP composites.	121
4.34	Bulk density for LD-PP and HD-PP of G/Sn/PP composites.	122
4.35	Shore hardness for LD-PP and HD-PP of G/Sn/PP composites.	123

## LIST OF APPENDICES

APPENDIX	TITLE	PAGE
A	Results for electrical conductivity, bulk density, shore hardness and flexural strength for Gr/Sn and Gr/Sn/PP composites	145

## LIST OF ABBREVIATIONS

AFC	-	Alkaline Fuel Cell
Al	-	Aluminum
ASTM	-	American Society for Testing and Material
BC	-	Before Century
CB	-	Carbon Black
CF	-	Carbon Fibre
CNT	-	Carbon Nanotubes
CPCs	-	Conductive Polymer Composites
CNC	-	Computer Numerically Controlled
Cu	-	Copper
DMFC	-	Direct Methanol Fuel Cell
DOE	-	Department of Energy
EDX	-	Energy Dispersive X-ray
FCV	-	Fuel Cell Vehicle
GDL	-	Gas Diffusion Layer
G	-	Graphite
H <sub>2</sub>	-	Hydrogen
H <sub>2</sub> O	-	Water
H <sub>3</sub> O <sup>+</sup>	-	Hydronium ion
HD-PP	-	High density- Polypropylene
ICPs	-	Intrinsically Conductive Polymers
KOH	-	Potassium Hydroxide
LD-PP	-	Low density- Polypropylene
MCFC	-	Molten Carbonate Fuel Cell
MEA	-	Membrane Electrolyte Assembly
Ni	-	Nickel

O <sub>2</sub>	-	Oxygen
OCP	-	Open Circuit Potential
PAFC	-	Phosphoric Acid Fuel Cell
Pb	-	Lead
PE	-	Polyethylene
PEM	-	Polymer Electrolyte Membrane
PEMFC	-	Polymer Electrolyte Membrane Fuel Cell
PM	-	Powder Metallurgy
PP	-	Polypropylene
PPS	-	Polyphenyl sulphide
PSU	-	Polysulfone
Pt	-	Platinum
PTFE	-	Polytetrafluoroethylene
PVDF	-	Polyvinylidene fluoride
SEM	-	Scanning Electron Microscope
Sn	-	Stannum
SnO <sub>2</sub>	-	Tin oxide
SOFC	-	Solid Oxide Fuel Cell
SS	-	Stainless Steel
Ti	-	Titanium
wt.%	-	Weight ratio

## LIST OF SYMBOLS

$\pi$	-	Pi
S	-	Distance of 3-point probe
v	-	Test data

## LIST OF PUBLICATIONS

Masron, F., Selamat, M.Z., Tahir, M.M., Daud, M.A.M., Sahari, J., 2016. Effect of Molding Temperature on Properties of Graphite/Stannum/Polypropylene Composites. *Proceedings of Mechanical Engineering Research Day 2016*, pp.59-160.

Selamat, M.Z., Masron, F., M. Yusuf, Kamarolzaman, A.A., 2014. Effect of Stannum on Properties of Graphite/Stannum Composite for Bipolar Plate. *Applied Mechanics and Materials*, 699, pp.157–162.