Preparation and Characterization of Epoxy/ Poly (Methyl Methacrylate) (PMMA) Blend System with Carbon Based Conductive Fillers.

by

PHUA JIN LUEN
(1340410911)

A thesis submitted in fulfilment of the requirement for the degree of Doctor of Philosophy in Materials Engineering

School of Materials Engineering
UNIVERSITI MALAYSIA PERLIS

2016

ACKNOWLEDGEMENT

First and foremost, I would like to express my sincerest gratitude to my supervisor, Dr. Teh Pei Leng, for the continuous support of my Ph.D. study and related research, for her patience, motivation, and immense knowledge while allowing me the room to explore in my way. Her willingness to give her time so generously has been very much appreciated. I would like to extend my very great appreciation to my co-supervisor, Assoc. Prof. Dr. Supri A. Ghani and the rest of my thesis committee, Dr. Yeoh Cheow Keat and Dr. Rozyanty Bt. Rahman, for their valuable and constructive suggestions during planning and development of this research work.

My grateful heart goes to our dean, Dr. Khairel Rafezi and the School of Materials Engineering, for providing an excellent research environment and well-functioned equipment. I would like to offer my heartfelt to Mr. Azmi Bin Kamardin for his guidance and knowledge sharing during my data collection processes. My sincere thanks to all the technicians of the School of Materials Engineering: Mr. Norzaidi Bin Zainol, Mr. Mohd Nasir Bin Haji Ibrahim, Mr. Ku Hasrin Bin Ku Abdul Rahman, Mr. Mohamad Safwan Bin Isa, Mr. Mohammed Faisal Rusli, Mr. Ahamd Hadzrul Bin Iqwan Jalaludin, Mr. Chek Idrus Bin Omar, Mr. Azmi Bin Aziz and Mr. Rosmawadi Bin Othman, for their helpful and patience attitudes in aiding me running my Laboratories works.

For this dissertation, I would like to thank my discussion group: Mohamad Nur Fuadi, Devi Shantini, Saw Lip Teng, Teo Siew Cheng, Lim Joon Hoong and much more, for their time, stimulating and insightful comments. I gratefully acknowledge the funding sources that made my Ph.D. work possible. Under the Malaysia Ministry of Higher Education, I was awarded MyBrain 15 Sponsorship Programme (MyPhD). Without their valuable support, it would be not possible to conduct this research. Lastly, I would like to thank my family for all their love and encouragement. For my parents who raised me and helped me in all my pursuits and to my sisters and brother for supporting me spiritually throughout this research and my life in general. Thank you.

Phua Jin Luen

Universiti Malaysia Perlis

June 2016

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF ABBREVIATIONS

0D	Zero dimensional
1D	One dimensional
2D	Two dimensional
3D	Three dimensional
ABS	Acrylonitrile-butadiene-styrene copolymer
Ag	Silver
ASTM	American Society for Testing and Materials
BET	Brunauer–Emmett–Teller Theory
CB	Carbon black
CNTs	Carbon nanotubes
CPC	Conductive polymer composites
CTE	Thermal expansion coefficient
DETA	Diethylene triamine
DM	Direct mixing
EVA	Ethylene vinyl acetate
FTIR	Fourier transform infrared spectroscopy
GIC	Graphite intercalation compound
GNP	Graphene nanoplatelet
GO	Graphene oxides
HAF	High abrasion furnace black
HIPS	High-impact polystyrene
HNO_3	Nitric acid
HPB	Homologous polymer blend
I.U.P.A.C.	International Union of Pure and Applied Chemistry
ICP	Intrinsically conductive polymer

KBr	Potassium bromide
K_{IC}	Fracture toughness
LDPE	Low density polyethylene
MAH	Maleic anhydride
MMA	Methyl methacrylates
MWD	Molecular weight distribution
MWNTs	Multi-walled nanotubes
MXDA	Meta-Xylenediamine
N-AEP	N- Aminoethylpiperazine
NH_2	Amino group
Ni	Nickel
PA	Polyacetylene
PA6	Polyamide 6
PAni	Polyaniline
PBT	Poly (butylene terephthalate)
PC	Polycarbonate
PEDOT	Poly (3,4-ethylenedioxythiophene)
PMMA	Poly (methyl methacrylate)
PP	Polypropylene
PPy	Polypyrrole
PS	Polystyrene
PTh	Polythiophene
PUR	Polyurethane
RPM	Rotor speed per minutes
r-GO	Reduced graphene oxide
SAN	Styrene acrylonitrile resin
SD	Solvent dissolution

SiC	Silicon carbide
SRF	Semi-reinforcing furnace black
SWNTs	Single-walled nanotubes
TEPA	Tetraethylenepentamine
TETA	Triethylene tetramine
Tg	Glass transition temperature
TGA	Thermogravimetric analysis
TiB_2	Titanium Diboride
UV	Ultraviolet
ZnO	Zinc oxide

LIST OF SYMBOLS

ΔG_m	Gibbs free energy of mixing
ΔH_m	Enthalpy of mixing
μm	micrometre
A	Cross-sectional area
a	Total notch length
b	Width of beam
B	Thickness of the sample
cm	centimetre
d	Depth of beam tested
dL/dT	Change of length of the sample per unit change in temperature
$f\left(\frac{a}{w}\right)$	Geometry correction factor
Fmax	Maximum force in the force-deflection trace
GPa	Giga pascal
L	Support span
L	Length of the sample
m	Slope of the tangent to the initial straight-line portion of the load deflection curve (N/mm)
M_f	Mass of filler
M_m	Mass of matrix
mm	millimetre
MPa	Mega pascal
nm	nanometre
P	Load at given point on the load-deflection curve (N)
R	Resistance
t	Thickness

TPa	Tera pascal
V_f	Volume fraction of filler
Vol.%	Volume percentage
W	Width of the sample
W_f	Weight fraction of filler
W_m	Weight fractions of matrix
Wt.%	Weight percentage
ρ_c	Density of composites
ρ_f	Density of filler
ρ_m	Density of matrix
Ω.cm	electrical resistivity
$\Omega^{-1}.cm^{-1}$	electrical conductivity
ω_F	quadratic function of the wave factor