



Faculty of Mechanical Engineering

**RELIABILITY PERFORMANCE OF EPOXY BASED
ELECTRICALLY CONDUCTIVE ADHESIVE WITH VARYING
MULTIWALLED CARBON NANOTUBE**

Muhamad Muaz bin Nasaruddin

Master of Science in Mechanical Engineering

2019

**RELIABILITY PERFORMANCE OF EPOXY BASED ELECTRICALLY
CONDUCTIVE ADHESIVE WITH VARYING MULTIWALLED CARBON
NANOTUBE**

MUHAMAD MUAZ BIN NASARUDDIN

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

Faculty of Mechanical Engineering

UNIVERSITI TEKNIKAL MALAYSIA MELAKA

2019

DECLARATION

I declare that this thesis entitled “Reliability Performance of Epoxy Based Electrically Conductive Adhesive with Varying Multiwalled Carbon Nanotube” 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 :

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 :

Date :

DEDICATION

To my beloved family

ABSTRACT

Over the last twenty years, there is a rapid development in microelectronic industries to support sustainable manufacturing globally, which includes the use of more environmental-friendly interconnect materials. Carbon-based ECA is proposed to replace conventional materials such as lead solder alloy (Sn/Pb), lead-free solder alloy (Sn/Ag/Cu) and metal-based ECA. Carbon-based ECA such as MWCNT filled adhesive offer toxicity-free, low processing temperature and oxidation free which can benefit the ECA in many aspects. However, MWCNT is known to constraint the ECA performance in terms of electrical properties. In addition, a polymer-based binder such as epoxy could deteriorate under elevated temperature and humid conditions. Hence, the main objectives of this study are to investigate the effect of filler loading and aspect ratio of multi-walled carbon nanotubes (MWCNTs) on the volume resistivity of ECA, to evaluate the effect of filler loading and aspect ratio of multi-walled carbon nanotubes on the adhesion strength of ECA and to assess the effect of hygrothermal aging on the volume resistivity and adhesion strength of ECA with varying filler loading and aspect ratio. 112.5 (L-MWCNT) and 1750.0 (H-MWCNT) are MWCNT aspect ratios considered in this study. Meanwhile, the range of MWCNT filler loading considered for the ECA is between 3 to 8 wt.%. A four-point probe was employed to evaluate the volume resistivity of ECA using ASTM F390 as a guideline. Meanwhile, a universal testing machine (UTM) was utilized to conduct the single-bonded joint test to evaluate the ECA adhesion strength in accordance with the ASTM D1002. In addition, hygrothermal aging test was performed by using an environmental chamber to assess the influence of severe environmental conditions towards the volume resistivity and the adhesion strength of ECA. Regardless of the range of filler loading, it was found that H-MWCNT filled ECA exhibits superior performance than those of the L-MWCNT in terms of the electrical conductivity and adhesion strength when subjected to hygrothermal aging up to 504 hours. As an example, at 5 wt.%, the H-MWCNT recorded lower volume resistivity than those of the L-MWCNT filled ECA, which could be attributed to its great flexibility which increased the filler tends to be in contact with each other. Consequently, better electron pathway is established within the ECA system, which yields an improved electrical conductivity. Moreover, the H-MWCNT filled ECA is approximately 34% stronger in adhesion strength than those of the L-MWCNT filled ECA, possibly due to an efficient stress distribution with longer tube length of the MWCNT filler. Nonetheless, when subjected to hygrothermal aging, both types of ECA exhibit a similar trend in which the volume resistivity increased, with the H-MWCNT being more resistant, possibly due to greater humidity barrier towards the moisture ingress into the ECA composite system. Overall, it can be concluded that higher aspect ratio of the MWCNT filled ECA exhibit better functional performance with and without the hygrothermal aging conditioning.

ABSTRAK

Sejak 20 tahun lepas, terdapat pembangunan yang mendadak dalam industri mikroelektronik sebagai menyokong kelangsungan pembuatan di peringkat global, termasuk penggunaan bahan penghubung yang mesra alam. ECA berasaskan karbon telah dicadangkan untuk menggantikan bahan penghubung konvensional seperti pateri aloi plumbum (Sn/Pb), pateri aloi bebas plumbum (Sn/Ag/Cu) dan ECA berasaskan logam. ECA berasaskan karbon seperti perekat yang diisi MWCNT mempunyai sifat bebas toksik, suhu pemrosesan rendah dan bebas pengoksidaan yang boleh memberi manfaat kepada ECA dalam banyak aspek. Namun, bahan ini mempunyai kelemahan dari segi prestasi sifat elektrik. Tambahan pula, bahan pengikat berasaskan polimer seperti epoksi boleh terjejas di bawah suhu dan kelembapan yang tinggi. Oleh itu, objektif utama kajian ini adalah untuk mengkaji kesan perbezaan memuat pengisi dan nisbah aspek MWCNT terhadap isipadu keberintangan ECA, untuk mengkaji kesan perbezaan memuat pengisi dan nisbah aspek MWCNT terhadap kekuatan rekatan ECA; dan untuk mengenalpasti kesan penuaan higrotermal terhadap isipadu keberintangan dan kekuatan rekatan ECA dengan memuat pengisi dan nisbah aspek yang berbeza. 112.5 (L-MWCNT) dan 1750.0 (H-MWCNT) adalah nisbah aspek MWCNT yang digunakan dalam kajian ini. Sementara itu, kadar memuat pengisi MWCNT untuk ECA adalah antara 3 hingga 8 wt.%. Empat titik kuar telah digunakan untuk menilai isipadu keberintangan ECA berpandukan ASTM F390. Sementara itu, mesin ujian semesta (UTM) digunakan untuk menjalankan ujian terikat tunggal bagi menilai kekuatan rekatan ECA berpandukan ASTM D1002. Tambahan pula, ujian penuaan higrotermal dijalankan dengan menggunakan kebuk persekitaran bagi mengkaji kesan keadaan sekeliling yang ekstrim terhadap isipadu keberintangan dan kekuatan rekatan ECA. Tanpa mengira kadar memuat pengisi, ECA yang diisi H-MWCNT memberikan prestasi yang luar biasa berbanding L-MWCNT dari segi keberaliran elektrik dan kekuatan rekatan apabila dikenakan penuaan higrotermal selama 504 jam. Sebagai contoh, pada 5 wt.%, H-MWCNT mencatatkan isipadu keberintangan yang rendah berbanding L-MWCNT, yang disebabkan kecemerlangan daya fleksibilitinya seterusnya meningkatkan kebarangkalian pengisi untuk bersentuhan antara satu sama lain. Hasilnya, laluan elektron yang lebih baik tercipta dalam sistem ECA, yang menyebabkan peningkatan dalam keberaliran elektrik. Tambahan pula, ECA diisi H-MWCNT dianggarkan mempunyai 34% lebih kekuatan rekatan berbanding L-MWCNT, berkemungkinan disebabkan oleh pembahagian tekanan yang lebih efisien hasil dari tiub MWCNT yang lebih panjang. Namun, apabila dikenakan ujian penuaan higrotermal, kedua-dua jenis ECA menunjukkan pola yang sama iaitu kenaikan isipadu keberintangan, dengan H-MWCNT yang mempunyai ketahanan yang lebih, berkemungkinan disebabkan oleh penghadang kelembapan yang baik daripada serangan kelembapan. Secara keseluruhan, ECA diisi nisbah aspek MWCNT yang tinggi menghasilkan prestasi fungsi dan ketahanan yang lebih baik dengan mahupun tanpa dikenakan penuaan higrotermal.

ACKNOWLEDGEMENTS

All praise to Allah The Almighty God for the strength and mercy in completing this research degree.

Deep appreciation also to my supervisor Dr. Siti Hajar binti Sheikh Md. Fadzullah, who guides me very well throughout this project. Under her supervision, I had gained lots of knowledge and experience that enable me to complete this research degree successfully. I would also like to convey my deepest gratitude to Prof. Dr. Ghazali bin Omar as my second supervisor.

In addition, I would thank Universiti Teknikal Malaysia Melaka (UTeM) especially Faculty of Mechanical Engineering (FKM) for the financial support for this work under PJP/2016/FKM/HI1/S01464 and G/Luar/JABIL/2016/FKM-CARe/I00016 research grants. Special thanks to Advanced Material Characterization Lab (AMCHAL) from FKM and Physic Lab from Faculty of Manufacturing Engineering (FKP) and all the staff for all technical support and assistance throughout my studies. Not to forget all my friends especially, Muhammad Azrain bin Mohammad who supported me in many ways and I will always remember these sweet memories of ours.

I would like to acknowledge Universiti Teknikal Malaysia Melaka (UTeM) Zamalah Scheme for the financial assistance.

Last but not least, I would like to send my love and appreciation to my family for their love, support and encouragement throughout this research degree.

TABLE OF CONTENTS

	PAGE
DECLARATION	
APPROVAL	
DEDICATION	
ABSTRACT	i
ABSTRAK	ii
ACKNOWLEDGEMENTS	iii
LIST OF TABLES	vi
LIST OF FIGURES	vii
LIST OF SYMBOLS	xii
LIST OF ABBREVIATIONS	xiv
LIST OF PUBLICATIONS	xvi
CHAPTER	
1. INTRODUCTION	1
1.1 Background study	1
1.2 Problem statement	4
1.3 Objectives	5
1.4 Scope of study	6
2. LITERATURE REVIEW	7
2.1 Introduction to electronic packaging	7
2.2 Interconnect materials	11
2.2.1 Lead-containing solder alloy	11
2.2.2 Lead-free solder alloy	13
2.3 Electrically conductive adhesives (ECA) interconnect materials	14
2.3.1 Polymer matrix for ECA	16
2.3.1.1 Epoxy	18
2.3.2 Filler for ECA	19
2.3.2.1 Metal filler	20
2.3.2.2 Non-metal filler	21
2.3.3 Carbon nanotube (CNT)	23
2.3.3.1 Geometry of CNT	23
2.3.3.2 Properties of CNT	24
2.4 Formulation of ECA	25
2.4.1 Effect of filler geometry	25
2.4.2 Effect of filler aspect ratio	27
2.5 Functional properties of ECA	29
2.5.1 Electrical properties	29
2.5.2 Mechanical properties	33
2.5.2.1 Tensile test	33
2.5.2.2 Lap shear test	38
2.5.2.3 Flexural test	48
2.5.2.4 Impact test	51
2.6 Reliability of ECA	55
2.7 Research Gap	61
2.8 Summary	62

3.	METHODOLOGY	63
3.1	Introduction	63
3.2	Raw materials	63
	3.2.1 Epoxy	65
	3.2.2 Hardener	65
	3.2.3 MWCNT	65
3.3	Sample preparation	66
	3.3.1 Preparation of ECA	66
	3.3.2 Sample preparation for electrical resistivity test	70
	3.3.3 Sample preparation for single-lap joint test	72
	3.3.4 Surface treatment of substrate	75
	3.3.5 Hygrothermal aging test	78
3.4	Electrical characterization	79
	3.4.1 Volume resistivity using four-point probe	79
3.5	Mechanical testing	80
	3.5.1 Single-lap bonded joints test	80
3.6	Thermal analysis	83
	3.6.1 Differential Scanning Calorimeter (DSC)	83
	3.6.2 Thermogravimetric Analysis (TGA)	84
3.7	Surface topography analysis	85
	3.7.1 Surface roughness measurement via surface profilometer	85
	3.7.2 Wettability study via contact angle measurement	86
3.8	Morphological study	87
	3.8.1 Optical Microscope	87
	3.8.2 Transmission Electron Microscope (TEM)	88
4.	RESULT AND DISCUSSION	89
4.1	Introduction	89
4.2	Characteristic of the MWCNT via TEM analysis	89
4.3	Electrical property of ECA with varying filler loading and aspect ratio	92
	4.3.1 The effect of filler loading and aspect ratio on ECA's volume resistivity	92
4.4	Interlayer strength of the ECA	97
	4.4.1 The effect of filler loading and aspect ratio on ECA's lap shear strength	97
	4.4.2 The effect of substrate surface condition on ECA's lap shear strength	103
4.5	Hygrothermal aging behaviour of the ECA	111
	4.5.1 Thermal characteristics	111
	4.5.2 The effect of hygrothermal aging on the volume resistivity of the ECA	113
	4.5.3 The effect of hygrothermal aging on the lap shear strength of the ECA	119
5.	CONCLUSION AND RECOMMENDATIONS	125
5.1	Conclusions	125
5.2	Recommendations for future work	127
	REFERENCES	128

LIST OF TABLES

TABLE	TITLE	PAGE
2.1	Material properties of Sn/Pb (Trinidad, 2016)	12
2.2	Resistivity of different interconnect materials with its loading (Wu et al., 2006)	25
2.3	Formulation of binary and ternary adhesive (Ji et al., 2015)	27
3.1	Details of the aspect ratio of the MWCNTs used in this research (Nanomor.com, 2018)	66
3.2	Formulation of the ECA	69
4.1	Volume Resistivity for the ECA with Varying Filler Loading and Aspect Ratio	93
4.2	ECA's lap shear strength of ECA with different filler loading when subjected to different surface conditioned	104
4.3	Optical microscope images of as-received, 180 grit grinded and chemical etched surface of substrate, at 200x magnification level	105
4.4	Results following contact angle measurement	109
4.5	Glass transition temperature of MWCNT with varying concentration and aspect ratio	111
4.6	Degradation temperature of MWCNT with varying concentration and aspect ratio	112
4.7	Volume resistivity data of ECA when subjected to three weeks of hygrothermal aging	114
4.8	Lap shear data of ECA when subjected to three weeks of hygrothermal aging	120

LIST OF FIGURES

FIGURE	TITLE	PAGE
1.1	An overview of the research scope	6
2.1	Assembly hierarchy of electronic packaging (Li, 2007)	8
2.2	Different interconnection methods in the first level of electronic packaging manufacturing (Li, 2007)	9
2.3	Diagrams showing the presence of functional components connections to the circuit board via interconnect materials	11
2.4	One of the product of lead-free solder alloys in the market	13
2.5	Typical percolation graph in ECA (Li, 2007)	14
2.6	SEM micrographs and schematic diagrams (a)(d) ICA, (b)(e) ACA and (c)(f) NCA (Li, 2007)	15
2.7	Chemical reaction to produce DGEBA (Pham and Marks, 2012)	19
2.8	Chemical compound of polyetheramine D230	19
2.9	SWCNT (Left) and MWCNT (Right) (Serra, 2012)	23
2.10	Armchair (top), zigzag (middle) and chiral (bottom) (Mantena, 2009)	24
2.11	Determining the aspect ratio of MWCNT	28
2.12	(a) Resistivity vs weight fraction and (b) weight fraction vs temperature (Zhou et al., 2016)	30
2.13	Volume resistivity against weight fraction of silver nanospheres (Han et al., 2016)	31
2.14	Resistivity vs MWCNT percent concentration (Yuen et al., 2007)	32
2.15	Dog-bone shape sample for tensile test according to ASTM D638 (Subramaniam et al., 2016)	34
2.16	Tensile strength against weight fraction of MWCNT in Epoxy (Omidi et al., 2010)	34
2.17	Tensile strength and Young's Modulus against weight fraction of MWCNT in Epoxy (Yeh et al., 2008)	35

2.18	Tensile fracture surface of (a) 0 wt.% and (b) 5 wt.% of MWCNT filled epoxy polymer (Yeh et al., 2008)	36
2.19	Tensile strength and Young's modulus of 0.5 wt.% MWCNT with different hardener concentration at (a) 9 wt.%, (b) 12 wt.% and (c) 13 wt.% (Ci and Bai, 2006)	37
2.20	Interface interaction between MWCNT and (a) soft and (b) stiff epoxy matrix (Ci and Bai, 2006)	38
2.21	Assembly of a single-bonded joint for lap shear test according to ASTM D1002	39
2.22	Types of failure in adhesive; (a) adhesive failure, (b) cohesive failure, (c) partial cohesive failure and (d) substrate failure (Correia et al., 2018)	39
2.23	(a) High and (b) low-viscosity of adhesive wetting behaviour on adherents' surface (Habenicht, 2009)	40
2.24	Improved adhesion strength by PDA as the surfactant solution, evident from changing of the failure modes (Subramaniam et al., 2016)	42
2.25	Bond line thickness of ECA in single lap joint test sample	45
2.26	Correlation between bond line thickness and bond strength (Czarnecki et al., 2012)	46
2.27	(a) Surface mounted component on substrate, (b) cross-section image of sample and (c) observation of segregation layer (Zhang and Agar, 2010)	47
2.28	Sample setup for the flexural test according to ASTM D790	48
2.29	Flexural strength of epoxy filled with 5 and 25 μm (Chatterjee et al., 2012)	49
2.30	Flexural modulus against ratio (CNT: GNP) (Chatterjee et al., 2012)	49
2.31	Sample assembly according to ASTM D6110	51
2.32	Impact resistance of various filler loading of epoxy filled MWCNT and ND (Subhani et al., 2015)	52
2.33	(a) MWCNT, (b) ND and (c) 0.2 wt.% of MWCNT and ND in an epoxy polymer (Subhani et al., 2015)	53
2.34	Impact strength of epoxy filled with MWCNT-COOH and MWCNT-COTETA at (a) 0 wt.% DER 736 and (b) 5 wt.% of reactive diluent (Silva et al., 2015)	54

2.35	Schematic diagram of a mounted 1068 chip on PCB (Sharma et al., 2017)	56
2.36	Cross-section SEM images of 1068 chip mounted on PCB after (a) 500 cycles and (b) 1000 cycles of thermal shock test (Sharma et al., 2017)	56
2.37	Shear strength of SAC 305 and SAC 305E after aged for 1000 cycles under thermal shock test (Sharma et al., 2017)	57
2.38	Shear strength of ECA under 1000 cycles of temperature cycle test (Gao et al., 2012)	58
2.39	Shear strength of ECA under 1000 hours of the hygrothermal aging test (Gao et al., 2012)	59
2.40	Contact resistance against hygrothermal aging time of different hybrid filler loading (Cui et al., 2013a)	60
2.41	Research gap in the current study	62
3.1	Flow chart of the experimental works	64
3.2	Flow chart of ECA sample preparation	67
3.3	Mixture of Araldite 506 Epoxy Resin and Polyetheramine D230 hardener: (a) cloudy solution and (b) clear solution	68
3.4	Thoroughly mix 5 wt.% MWCNT in the mixture of epoxy resin and hardener	69
3.5	Printing arrangement of ECA on acrylic substrate	70
3.6	ECA sample preparation for electrical conductivity test: (a) taped acrylic substrate and (b) ECA after the printing process	71
3.7	Finished sample and ready for the electrical conductivity test	71
3.8	Schematic diagram of single-lap bonded joint test sample	72
3.9	The assembly of single-lap joint jig	73
3.10	Fabrication of test sample by using the jig	74
3.11	Finish sample of single-lap bonded joint	74
3.12	Examples of silicon carbide grit papers	75
3.13	Grinder-polisher model Nano 2000T from Pace Technologies	76
3.14	Chemical etching process of aluminium substrates	77
3.15	Flow diagram of the chemical etching process in aluminium substrate	77
3.16	Memmert Humidity Chamber Model HCP 108	78
3.17	Jandel In-Line Four Point Probe with RM3000+ Test Unit	79

3.18	(a) Schematic diagram of modified test sample and (b) final appearance of single-lap bonded joint test	81
3.19	Universal testing machine Model Hengzhun HZ-1003	81
3.20	Clamping position of the sample at the test jig	82
3.21	Perkin Elmer, Jade DSC	83
3.22	TGA model Q50 from TA Instrument	84
3.23	(a) Mitutoyo SJ-410 Profilometer and (b) close up image of stylus head	85
3.24	Experiment set up for water droplet contact angle measurement	86
3.25	Contact angle measurement on the water droplet	87
3.26	Optical microscope of Axioskop 2 Mat, Carl Zeiss	87
3.27	TEM brand Tecnai G2 F20	88
4.1	TEM Micrograph Showing the Short MWCNT (L-MWCNT)	90
4.2	TEM Micrograph of flawed short MWCNT (L-MWCNT) spotted	91
4.3	TEM Micrograph showing the long MWCNT (H-MWCNT)	91
4.4	TEM images of flawed long (H-MWCNT) spotted	92
4.5	Volume resistivity for the H-MWCNT/Epoxy and L-MWCNT/Epoxy	93
4.6	TEM micrographs of controlled amount of MWCNT particles arrangement for (a) low aspect ratio (L-MWCNT) and (b) high aspect ratio (H-MWCNT)	94
4.7	Lap shear strength of MWCNT-filled epoxy as a function of filler loading and aspect ratio	98
4.8	(a) High and (b) low-viscosity of adhesive wetting behaviour on adherents' surface	100
4.9	Digital microscope images of the mode of failure for (a) L-MWCNT/Epoxy and (b) H-MWCNT/Epoxy	102
4.10	Lap shear strength of ECA with different substrate surface conditioned at different filler loadings	103
4.11	Plot of surface roughness measurement for (a) as-received, (b) 180 grit grinded and (c) chemical etched substrate surface using Mitutoyo SJ-410 Profilometer	108
4.12	Illustration of a water droplet on (a) ground and (b) chemically etched surface condition	110

4.13	Volume resistivity against the aging time of (a) L-MWCNT/Epoxy and (b) H-MWCNT/Epoxy	114
4.14	Schematic diagram of moisture attack on ECA filled with different (a) MWCNT concentration and (b) MWCNT aspect ratio	116
4.15	Water uptake by ECA for three weeks of hygrothermal aging	116
4.16	Hygroscopic expansion of ECA	118
4.17	Lap shear strength H-MWCNT/epoxy and L-MWCNT/epoxy following three weeks of hygrothermal aging	120
4.18	Schematic diagram of moisture attack effect towards the single-lap joint	121
4.19	Mode of failures for L-MWCNT/Epoxy at 5 wt.% with different aging time as observed through digital camera	122
4.20	Mode of failures after 3 weeks of aging time at 6 wt.% of low and high MWCNT aspect ratio as observed through digital camera	123

LIST OF SYMBOLS

L_{\max}	-	Maximum allowable length for overlap area
F_{ty}	-	Yield point of substrate
t	-	Thickness of substrate
τ	-	50% estimated lap shear strength
X_c	-	Composite property
X_m	-	Matrix property
X_f	-	Filler property
V_m	-	Matrix volume fraction
V_f	-	Filler volume fraction
W_m	-	Matrix weight fraction
w_m	-	Matrix weight
w_c	-	Composite weight
W_f	-	Filler weight fraction
w_f	-	Filler weight
ρ	-	Volume resistivity
V	-	Output voltage
I	-	Input current
G	-	Correction factor
t_s	-	Sample thickness
τ_{Lap}	-	Maximum lap shear strength
F_{\max}	-	Maximum tensile force

A	-	Adhesive overlap area
L_c	-	Fibre critical length
σ_f	-	Fibre tension strength
d	-	Fibre diameter
τ_c	-	Shear strength of fibre-matrix interface

LIST OF ABBREVIATIONS

ACA	-	Anisotropically Conductive Adhesive
ASTM	-	American Society for Testing and Materials
BN	-	Boron Nitride
CMC	-	Critical Micelle Concentration
COOH	-	Carboxylic Acid
DSC	-	Differential Scanning Calorimeter
ECA	-	Electrically Conductive Adhesive
GNP	-	Graphene Nanoplatelets
HCL	-	Hydrochloric Acid
H-MWCNT	-	High Aspect Ratio of Multiwalled Carbon Nanotube
IC	-	Integrated Chip
ICA	-	Isotropically Conductive Adhesive
L-MWCNT	-	Low Aspect Ratio Multiwalled Carbon Nanotube
MF	-	Microflake
MWCNT	-	Multiwalled Carbon Nanotube
ND	-	Nanodiamond
NS	-	Nanosphere
NCA	-	Nonconductive Adhesive
NaOH	-	Sodium Hydroxide
PCB	-	Printed Circuit Board

PDA	-	Polydopamine
SEM	-	Scanning Electron Microscope
SWCNT	-	Singlewalled Carbon Nanotube
TAB	-	Tape-Automated Bonding
TEM	-	Transmission Electron Microscope
TGA	-	Thermogravimetric Analysis

LIST OF PUBLICATIONS

1. Nasaruddin, M.M., Fadzullah, S.H.S.M. and Omar, G, 2019. Preliminary investigation on multi-walled carbon nanotubes filled epoxy composite as electrically conductive adhesive. *International Journal of Recent Technology and Engineering (IJRTE)*, 8(1S5), pp. 28-32. (Published).
2. Nasaruddin, M.M., Fadzullah, S.H.S.M., Omar, G, Mustafa, Z., Ramli, M.B., Akop, M.Z. and Mohamad, I.S., 2019. The effect of aspect ratio on multi-walled carbon nanotubes filled epoxy composite as electrically conductive adhesive. *Journal of Advanced Manufacturing Technology (JAMT)*, 13(1). (Published).
3. Othman, M.A., Fadzullah, S.H.S.M., Nasaruddin, M.M., Omar, G., and Akop, M.Z., 2018. Effect of temperature on reliability performance of electrically conductive nano-composites. In *1st Colloquium Paper: Advanced Materials and Mechanical Engineering Research (CAMMER'18)*, 1, pp. 38. Penerbit Universiti, Universiti Teknikal Malaysia Melaka.

4. Raheem, A.M.A., Fadzullah, S.H.S.M., Nasaruddin, M.M., Omar, G., and Akop, M.Z., 2018. Effects of carbon nanotube aspect ratio on the functional properties of electrically conductive adhesive. In *1st Colloquium Paper: Advanced Materials and Mechanical Engineering Research (CAMMER'18)*, 1, pp. 40. Penerbit Universiti, Universiti Teknikal Malaysia Melaka.

5. Rahman, W.A.W.A., Fadzullah, S.H.S.M., Nasaruddin, M.M., Omar, G., and Ramli, M.B., 2018. The effect of substrate surface conditions on mechanical performance of electrically conductive adhesive. In *1st Colloquium Paper: Advanced Materials and Mechanical Engineering Research (CAMMER'18)*, 1, pp. 46. Penerbit Universiti, Universiti Teknikal Malaysia Melaka.

CHAPTER 1

INTRODUCTION

1.1 Background study

In the world that we live today, there is a great dependency on electrical devices for numerous activities and requirements, be it for personal life or for work. Therefore, with such a growing demand, the semiconductor electronic industries are working a long way to provide advancement in the manufacturing and assembly of electronic packaging. Several parts are identified to be critical in fulfilling the growing needs especially in higher performance computing that involves multi and complex tasks in a single computer, while at the same time, need to be maintained in a limited dimension. Consequently, evolution of technology especially in chip assembly and interconnect materials are extensively growing and improved to support the changes while not compromising the functionality and reliability of the electronic product (Trinidad, 2016).

On the other hand, a shorter product life cycle of electronic components as a result of mass production which is due to the hasty growing of technology has caused the electronic packaging to be thrown away in landfills as electronic waste (e-waste) (Lewis and Ryan, 2008; Ma and Suhling, 2009). At the initial stage of the electronic packaging industry, most of the interconnect materials used are consist of lead (Pb) which is high in toxicity, as one of the main constituent materials (Chew et al., 2014). Moreover, an abundance of e-waste with improper disposal which can harm the environment and human health (Abtew and Selvaduray, 2000; Yim et al., 2009).

Consequently, the key players in this field, either the electronic industries manufacturers or researchers are actively working on the solutions to overcome the pertaining issues. Therefore, the first alternative for the interconnect materials is the introduction of SAC solder alloys which consist of Tin, Silver, and Copper (Sn, Ag and Cu) and also known as lead-free solder alloys (Abtew and Selvaduray, 2000; Jiang et al., 2006). SAC solder is regarded as a reliable lead solder replacement material due to its toxicity free and available in the world market today. However, lead-free solder has a higher melting temperature, which is near 220 °C, compared to 183°C for lead solder. Furthermore, during solder reflows process, the temperature will be increased way above the melting temperature of solder materials. In such lead-free solder alloys cases, the reflow temperature can reach up to 260 °C or higher. This extremely high temperature will restraint its usage for specific applications, especially during the manufacturing of heat-sensitive electronic components such as organic/polymer packaging or low-cost PCBs. A common plastic substrate will deform its physical condition in the temperature range of 150 °C to 200 °C (Naghdi et al., 2018). This process will eventually increase the possibility of product defects even at the early stage of manufacturing processes. In addition, a high-temperature requirement for the processes will also increase the energy consumption in the industry which consequently expand the production cost, damage the environment and cause reliability problems (Ma and Suhling, 2009; Zhang and Agar, 2010), can be regarded as the major drawback of using such alternative material for the electronic packaging.

Due to the issues with both interconnect materials mentioned; lead and lead-free solder alloys, the effort has shifted towards polymer-based conductive materials to restore and become the leading materials as the interconnect materials in electronic packaging. The polymer-based conductive adhesive is commonly known as electrically conductive adhesives (ECAs), free from toxic material and also capable of being processed at low