

THE EFFECT OF SUBSTRATE SURFACE CONDITIONS ON MECHANICAL PERFORMANCE OF
ELECTRICALLY CONDUCTIVE ADHESIVES

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UNIVERSITI TEKNIKAL MALAYSIA MELAKA

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PERFORMANCE OF ELECTRICALLY CONDUCTIVE ADHESIVES**

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In fulfillment of the requirements for the degree of
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DECLARATION

I declare that this project report entitled “The Effect of Substrate Surface Conditions on Mechanical Performance of Electrically Conductive Adhesives” is the result of my own work except as cited in references.

Signature :

Name :

Date :

APPROVAL

I hereby declare that I have read this project report and in my opinion this report is sufficient in terms of scope and quality for the award of the degree of Bachelor of Mechanical Engineering (Hons).

Signature :

Supervisor's Name :

Date :

DEDICATION

This report is dedicated to my beloved mother,
Maria Binti Hasan Basri

ABSTRACT

Nowadays, with increasing awareness to protect the environment, the use of lead-based solder for electronic components interconnection in printed circuit board (PCB) are gradually replaced by the lead-free electrically conductive adhesive (ECA) in microelectronic industry. As interconnect materials, the mechanical strength of ECA is another aspect to be improvised in addition to the electrical conductive performance. This research project investigates the effect of substrate surface treatment in terms of the surface roughness and surface wettability which contributed to shear strength of multi-walled carbon nanotube (MWCNT) filled ECA bonded to aluminium-aluminium substrate, and the effect of varying MWCNT filler loading on ECA mechanical and electrical properties. Surface roughness is measured using a stylus profilometer and the contact angle test is conducted to measure aluminium substrate surface wettability. The result of four-point probe test reveals that the sheet resistance of the ECA decreased with an increase in the MWCNT filler loading from 5 wt.% to 7 wt.%, due to enhanced formation of percolated linkages between MWCNT particles. Surface treated, and untreated aluminium substrate were used as substrate for single-lap shear adhesively bonded experiment. The surface treatments consist of grinding with silicone carbide (SiC) abrasive paper grit 180 and alkaline/acidic etching. The mechanical properties of ECA bonded to as-received and chemically etched aluminium substrates show an increase in shear strength with an increase MWCNT filler loading from 5 wt.% to 6 wt.% and decrease in shear strength with an increase of MWCNT filler loading from 6 wt.% to 7 wt.%. Higher shear strength is obtained when the ECA experience an adhesive-cohesive failure as compared to the adhesively failed ECA. The surface morphology study on fractured surface of ECA following lap shear test reveals high density of hollow structures/voids on the entire surface of ECA with 7 wt.% MWCNT filler loading, possibly due to agglomeration of MWCNT in the composites, which results in poorer mechanical properties. Overall, the alkaline/acidic etched aluminium substrate exhibit the highest surface roughness and the highest wettability as compared to other surface conditions which results in largest effective bond area between ECA/substrate interface, hence, highest shear strength of the ECA is obtained. Meanwhile, the grinded aluminium substrate with SiC abrasive paper grit 180 has the lowest wettability and slightly higher surface roughness than as-received aluminium substrate which yield to the lowest shear strength of the ECA. This is due to low degree of wettability of grinded aluminium substrate which yield in the low effective bond area, results in an insufficient anchoring of ECA towards the substrate surface.

ABSTRAK

Pada masa kini, peningkatan kesedaran terhadap penjagaan alam sekitar telah menyebabkan penggunaan pateri berasaskan plumbum untuk penyambungan antara komponen-komponen elektronik pada “printed circuit board” (PCB) telah digantikan secara berperingkat kepada “electrically conductive adhesive” (ECA) yang bebas plumbum dalam industri mikroelektronik. Sebagai bahan penyambung antara komponen elektronik, kekuatan mekanikal ECA perlu ditingkatkan selain daripada keupayaan mengalirkan elektrik. Projek penyelidikan ini dijalankan untuk mengkaji kesan rawatan permukaan terhadap kekasaran dan kebolehasahan permukaan yang memberi kesan terhadap kekuatan ricih ECA komposit yang mengandungi “multi-walled carbon nanotube” (MWCNT) apabila disambungkan pada dua permukaan substrat aluminium, dan kesan perbezaan kandungan MWCNT terhadap sifat mekanikal dan elektrik ECA. Stylus profilometer digunakan bagi mengukur kekasaran permukaan dan ujian sudut sentuhan dijalankan bagi menguji kebolehasahan permukaan substrat aluminium. Keputusan ujian empat titik pemeriksaan menunjukkan rintangan lembaran pada ECA mencatatkan penurunan dengan peningkatan kandungan MWCNT daripada 5 wt.% kepada 7 wt.% yang disebabkan oleh peningkatan hubungan dan sentuhan antara partikel MWCNT. Substrat aluminium yang dirawat dan tidak dirawat digunakan untuk ujian tegangan ricih pada dua permukaan aluminium yang dilekatkan. Rawatan permukaan terdiri daripada dua teknik iaitu mencanai dengan menggunakan kertas pengikis “silicon carbide” (SiC) grit 180 dan hakisan alkali/asid pada permukaan substrat aluminium. Kekuatan ricih ECA yang disambungkan pada aluminium substrat yang tidak dirawat dan yang dirawat dengan hakisan kimia meningkat dengan peningkatan kandungan MWCNT daripada 5 wt.% kepada 6 wt.% dan kekuatan ricih ECA menurun dengan peningkatan kandungan MWCNT daripada 6 wt.% kepada 7 wt.%. ECA yang gagal dengan lekatan-kohesif menunjukkan kekuatan ricih yang lebih tinggi berbanding ECA yang gagal pada lekatan. Kajian morfologi terhadap permukaan ECA dengan 7 wt.% kandungan MWCNT yang gagal setelah dikenakan tegangan ricih menunjukkan permukaan yang padat dengan struktur berlubang yang mungkin disebabkan berlakunya timbunan MWCNT, seterusnya mengurangkan kemampuan lekatan pada substrat. Secara keseluruhan, aluminium substrat yang dikenakan rawatan hakisan alkali/asid mempunyai kebolehasahan dan kekasaran permukaan yang tertinggi berbanding permukaan substrat yang lain, seterusnya menyumbang kepada permukaan efektif pada sambungan yang terluas antara permukaan ECA/substrat, justeru, kekuatan ricih yang tertinggi pada ECA tercapai. Sementara itu, permukaan aluminium yang dicanai dengan kertas pengikis SiC grit 180 mempunyai kebolehasahan permukaan yang terendah dan kekasaran permukaan lebih sedikit berbanding permukaan substrat aluminium yang tidak dirawat, seterusnya menyumbang kepada kekuatan ricih yang terendah pada ECA. Hal ini disebabkan oleh kebolehasahan permukaan yang rendah menyebabkan permukaan efektif pada sambungan menjadi rendah, seterusnya menyebabkan pautan tidak mencukupi oleh ECA untuk melekat pada permukaan substrat.

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TABLE OF CONTENTS

	PAGE
DECLARATION	
APPROVAL	
DEDICATION	
ABSTRACT	i
ABSTRAK	ii
ACKNOWLEDGEMENT	iii
TABLE OF CONTENTS	iv
LIST OF TABLES	vii
LIST OF FIGURES	ix
LIST OF APPENDICES	xiii
LIST OF ABBREVIATIONS	xiv
LIST OF SYMBOLS	xv
CHAPTER	
1. INTRODUCTION	1
1.1 Background	1
1.2 Problem statement	2
1.3 Objective	4
1.4 Scope of project	4
1.5 Planning and execution	4
2. LITERATURE REVIEW	8
2.1 Introduction	8
2.2 Electrically conductive adhesive (ECA)	8
2.2.1 Polymer matrix for ECA composites	9
2.2.1.1 Thermoplastic	9
2.2.1.2 Thermosets	10
2a.1 Epoxies	10
2.2.2 Fillers for ECA composites	11
2.2.2.1 Metal	12
2b.1 Gold	12
2b.2 Silver	12
2b.3 Copper	13
2.2.2.2 Non-metal	14
2c.1 Carbon nanotube (CNT)	14
2c.1.1 Single-walled carbon nanotube (SWCNT)	15
2c.1.2 Multi-walled carbon nanotube (MWCNT)	15
2.3 Properties of ECA	16
2.3.1 Electrical conductivity	16
2.3.2 Mechanical properties	22
2.3.2.1 Effect of ECA filler loading on ECA mechanical properties	24
2.3.2.2 Effect of surface conditions on ECA mechanical properties	27
2.3.2.3 Mode of failure	33
2.4 Properties of aluminium substrate	34

2.4.1 Wettability	35
2.4.2 Surface roughness	37
2.5 Substrate surface treatment	38
2.5.1 Chemical etching	38
2.5.2 Grinding with silicon carbide (SiC) abrasive paper	41
3. METHODOLOGY	42
3.1 Overview of research	42
3.2 Substrate surface treatment	43
3.2.1 Surface roughening with SiC abrasive paper grit 180	44
3.2.2 Chemical etching	45
3.3 Surface analysis	49
3.3.1 Surface morphology	49
3.3.1.1 Scanning electron microscopy (SEM)	50
3.3.1.2 Optical microscope	52
3.3.1.3 3D optical profilometer	54
3.3.2 Surface topography	55
3.3.2.1 Stylus profilometer	55
3.3.3 Contact angle test	57
3.4 ECA preparation	59
3.5 Fabrication of single-lap-joint	66
3.6 Fabrication of printed ECA on substrate	68
3.7 Conductivity performance	70
3.7.1 Four-point probe test	70
3.8 Mechanical properties	71
3.8.1 Lap shear test	71
3.8.2 Analysis on failure mode	74
4. RESULTS AND DISCUSSION	75
4.1 Introduction	75
4.2 Electrical performance of ECA with varying filler loading	75
4.2.1 The effect of filler loading on ECA sheet resistance	76
4.3 Aluminium substrate surface characterizations	78
4.3.1 Optical microscopy	79
4.3.2 3D surface profile	81
4.3.3 Surface roughness	82
4.3.4 Contact angle test	85
4.4 Interlayer strength of ECA	86
4.4.1 The effect of filler loading on ECA shear strength	86
4.4.2 The effect of substrate surface condition on ECA shear strength	89
4.5 ECA failure analysis	93
4.5.1 Mode of failure	93
4.5.2 Morphology study on surface of fractured ECA	96
4.5.2.1 Scanning electron microscopy (SEM)	96
4.6 Chapter summary	98
5. CONCLUSION AND RECOMMENDATIONS FOR FUTURE WORK	100

5.1 Conclusion	100
5.2 Recommendation for future works	101
REFERENCES	103
APPENDIX	113

LIST OF TABLES

TABLE	TITLE	PAGE
3.1	Chemical etching material and function	45
3.2	ECA components and function details	59
3.3	Epoxy resin specifications	60
3.4	Property and specifications of hardener	61
3.5	MWCNT specifications	62
3.6	MWCNT dimension specifications with aspect ratio details	62
3.7	ECA formulation for different filler loading	63
4.1	MWCNT filler loading and average sheet resistance of ECA	76
4.2	Microscopic images of surface morphology of different substrate surface conditions	80
4.3	3D profile image of different substrate surface conditions	82
4.4	Aluminium substrate surface conditions with the average surface roughness	83
4.5	Water droplet behaviour on different substrate surface conditions and the average contact angle	86

4.6	Result of single-lap-joint, contact angle and surface roughness for different substrate surface conditions	90
4.7	ECA with 5 wt.% MWCNT filler loading mode of failure	94
4.8	ECA with 6 wt.% MWCNT filler loading mode of failure	95
4.9	ECA with 7 wt.% MWCNT filler loading mode of failure	96
4.10	Comparison of ECA with different filler loading on chemically etched substrate	97

LIST OF FIGURES

FIGURE	TITLE	PAGE
1.1	Gantt chart of research activities for PSM 1	6
1.2	Gantt chart of research activities for PSM 2	7
2.1	Reaction process to produce bisphenol-A epoxy	10
2.2	Illustration of single-walled and multi-walled carbon nanotube	15
2.3	Series of resistance in ECA which consist of constriction resistance (R_c), tunnelling resistance (R_t) and filler resistance (R_f)	18
2.4	Bulk resistivity of solvent-free and solvent-assisted ECAs with different formulation which are 40 wt.% Ag/0.75 wt.% Gr(s) and 60 wt.% Ag/0.75 wt.% Gr(s)	20
2.5	Bulk resistivity for 45 wt.%, 52 wt.%, 57 wt.%, 66.5 wt.% and 72 wt.% Ag with various MWCNT loading or without any MWCNT added	21
2.6	Substrate and adhesives of lap shear test method based on ASTM D1002 as a standard guideline	23
2.7	Four different type of failure in single-lap-joint test	34
2.8	Liquid wet on solid surface with surface energies of solid-liquid, liquid-gases and solid-gases interfaces which described as $\gamma_{SG}, \gamma_{LG}, \gamma_{SL}$ respectively	36

2.9	Aluminium surface after undergoes alkaline/acid etching process: C1 ((a), (d)); C2 ((b), (e)); and C3 ((c), (f))	40
3.1	Flow chart of the research activities	43
3.2	Water prove SiC abrasive paper was used for mechanical abrasion surface treatment	44
3.3	Grinder and polishing machine for substrate surface treatment	45
3.4	NaOH granules was mixed with distilled water inside the round bottom flask	46
3.5	Thermometer was partially submerged into NaOH solution	47
3.6	The complete set up of chemical etching process	48
3.7	Air bubbles formed as the NaOH solution react to aluminium surface	48
3.8	Flow diagram of chemical etching process on aluminium substrate	49
3.9	Samples of fractured ECA on specimen holder	52
3.10	Auto-Fine Coater brand JEOL JEC-3000FC	52
3.11	Low power microscope brand ZEISS Axioskop 2 MAT	53
3.12	3D optical profilometer brand Shodensha GR3400	54
3.13	Mitutoyo SJ-410 profilometer used to measure surface roughness of aluminium substrate	56
3.14	Stylus head touch on the substrate surface	57
3.15	Surface contact angle experiment was set up inside the box	58
3.16	Contact angle measured at the right side of water droplet	59
3.17	Epoxy, hardener and multiwalled carbon nanotubes inside moulded glass container align with their specified plastic spoons	64

3.18	The flow process of ECA preparation	64
3.19	Digital weight balancing used for high accuracy of mass measurement	65
3.20	Fabrication process of single-lap-joint jig	66
3.21	Illustration of the process to fabricate aluminium single-lap-joint adhesively bonded	67
3.22	Single-lap-joint adhesively bonded samples are put into oven for ECA curing process	68
3.23	Polycarbonate substrate with dimensions	68
3.24	The dispersion of ECA on polycarbonate substrate	69
3.25	Printed ECA on polycarbonate sheet	69
3.26	Illustration of 6-printed ECA on substrate with dimensions	70
3.27	JANDEL In-Line 4 Point Probe test equipment	71
3.28	Dimension of single-lap-joint ECA bonded to Al-Al substrates	72
3.29	The dimension (in mm) of single-lap-joint sample with small aluminium plate placed on the grip area	73
3.30	Universal Material Testing (AG-10kNX) used for lap shear test	73
4.1	Graph of ECA average sheet resistance against percentage of MWCNT filler loading	76
4.2	Effect of volume fraction of MWCNT filler on the resistivity of ECA system	78
4.3	Graph of surface roughness against type of surface treatment applied on aluminium substrate surface	83

4.4	Surface profile of aluminium substrates: (a) grinded with silicon carbide paper G180, (b) chemically etched, and (c) as-received	84
4.5	Plot of shear strength against filler loading of ECA bonded to as-received aluminium substrate	88
4.6	Graph of lap shear strength of ECA against MWCNT filler loading	89
4.7	Illustration of ECA bonded to aluminium substrates with (a) voids with wide opening structures, and (b) sharp peaks and deep voids	92

LIST OF APPENDICES

APPENDIX	TITLE	PAGE
A	Results of contact angle test	113
B	3D profiles of aluminium substrate surface	115
C	Safety data sheet: Araldite® 506 epoxy resin	118
D	Technical bulletin: JEFFAMINE® D-230 Polyetheramine	125
E	Material safety data sheet: Carbon nanotubes	127

LIST OF ABBREVIATIONS

LSS	-	Lap Shear Strength
ECA	-	Electrically Conductive Adhesive
CNT	-	Carbon Nanotube
SWCNT	-	Single-Walled Carbon Nanotube
MWCNT	-	Multi-Walled Carbon Nanotube
ACA	-	Anisotropically Conductive Adhesive
ICA	-	Isotropically Conductive Adhesive
PCB	-	Printed Circuit Board
CTE	-	Thermal Coefficient of Expansion
NJ	-	New Joint
RJ	-	Repaired Joint
NaOH	-	Sodium Hydroxide
HCl	-	Hydrochloric Acid
SiC	-	Silicon Carbide
SEM	-	Scanning Electron Microscopy

LIST OF SYMBOLS

λ	-	Thermal conductivity, W/(m. K)
phr	-	Parts per hundred
Ra	-	Surface roughness, μm
γ_{SG}	-	Free energy per unit area of solid-gas, mJ/m^2
γ_{LG}	-	Free energy per unit area of liquid-gas, mJ/m^2
γ_{SL}	-	Free energy per unit area of solid-liquid, mJ/m^2
dA	-	Area covered by the liquid, m^2
θ	-	Contact angle
C_1	-	Percentage HCL in distilled water
V_1	-	Volume of HCL solution
C_2	-	Desired percentage of HCL in distilled water
V_2	-	Desired volume of HCL solution, $V_1 + V_{\text{Distilled Water}}$
V_m	-	Matrix volume fraction
V_f	-	Filler volume fraction
R_s	-	Sheet resistance ($\frac{\Omega}{\text{sq}}$)
G	-	Correction factor = 1.9475

V	-	Voltage
I	-	Input Current
τ_{Lap}	-	Lap Shear Strength, LSS (MPa)
F_{Max}	-	Maximum tensile force (N)
A	-	Adhesive overlap area (m ²)
R_f	-	Filler resistance
R_t	-	Tunnelling resistance
R_c	-	Constriction resistance
d	-	Particle diameter
D	-	Contact diameter
ρ	-	Intrinsic resistivity
ρ_t	-	Tunnelling resistivity
ε	-	Dielectric of the thin film
s	-	Thickness of the thin film
Φ	-	Work function of the metal fillers

CHAPTER I

INTRODUCTION

1.1 Background

Electrically conductive adhesives (ECAs) are basically made up from combination of adhesives such as epoxy-resin and metallic or carbon conductive filler. The contact between substrate and ECA allow current flow through them which conductive fillers, allowing electron movement by their contact between their suspended particles in the adhesives (Yi, Daniel, & C.P., 2010). High volume of conductive filler in ECA will give good electrical conductivity but will reduce the mechanical strength of the ECA and vice versa (H. P. Wu et al., 2007). There are few advantages of using ECA as compared to lead-based solder for electronic component interconnection, the adhesives are lead-free, less and simple processing steps which reduce production cost, and finer pitch due to the small particles of filler (Mantena, 2009).

ECA is divided into two types which are isotropically conductive adhesive (ICA) and anisotropically conductive adhesive (ACA). ICA has capability to conduct electric at all direction while ACA able to conduct electric at single direction which normally at z-axis. Various kind of ICA are made up from thermosetting resin. Thermosetting resin has several advantages on its properties such as high adhesives strength, and high resistance to chemical and corrosion. Conductive filler usually used in ICAs are nickel, copper, gold and carbon with different size and shape. ACAs are made up from pastes or films of thermoplastic which need high pressure and heat during bonding process to substrate. ACAs are not electrically conductive

before bond to substrate as the ratio of conductive filler to adhesives is low and below the percolation threshold (D. D. Lu & Wong, 2009).

In ICA, conductive pathways consist of genuine conduction and percolation. Genuine conduction is conduction by particle-to-particle contact in ICAs while percolation conduction is by dielectric breakdown of the matrix which electron is transmitted by quantum-mechanical electron tunnelling between nearby particles. Besides, ICA electrical conductivity performance also contributed by the uniform dispersion of filler particles in order to create excellent conductive pathway (Mantena, 2009).

1.2 Problem statement

The use of lead-based solder for electronic components interconnection in printed circuit board (PCB) are widely used in microelectronic industry. As the awareness to environment increase, the use of lead material for component interconnection is not recommended; hence a substitute material, that is lead-free electrically conductive adhesive (ECA) is introduced. Other alternative besides the ECA is lead-free solder alloys; nonetheless one of the main concern is on its melting temperature, which exceeds the design temperature of various types of circuit board (Brien, Us, & Ashmead, 2005). Moreover, compared to lead and lead-free solder, the processing temperature of ECA is the lowest and below the design temperature of many circuit board.

ECA is typically consist of polymer matrix binder such as epoxy resin and conductive filler material. In the last couple of years, the carbon nanotube (CNT) has been introduced to replace the use of metallic material as conductive filler. The use of CNT can increase the performance and properties of ECA. The improvements of ECA when using CNT as a filler instead of metallic material are in terms of an improved strength and modulus, high thermal

conductivity and good thermal stability, and high capacity of current flow (Kwon, Yim, Kim, & Kim, 2011).

The critical aspect in fine-pitch interconnection field is the adhesion strength of the ECA. This is because ECA is detrimental to shock encountered during handling, assembly and lifetime which require excellent adhesion bond between ECA/substrate interface. Basically, the overall adhesion strength of ECA is from two types of adhesion mechanisms; these being the chemical and physical bonding.

Chemical bonding requires chemical reaction between polymer and substrate which involve the formation of ionic or covalent bonds to link between the substrate and the polymer while physical bonding involve mechanical interlocking between ECA/substrate interface. The formation of inter-diffusion layer established as the interaction of polymer molecule that is highly compatible with the molecules of substrate occur. Besides, the polymer is expected to has good adhesion strength towards the substrate with a rougher surface in which rougher surface provide more contact surface area between polymer/substrate interface to establish excellent interfacial mechanical interlocking (Yi et al., 2010).

However, surface roughness may not establish good adhesion strength at the polymer/substrate interface if the polymer does not penetrate well into the rough surface asperities, which results in a decrease in the effective bond area and generate stress risers at the interface (Boutar, Naïmi, Mezlini, & Ali, 2016). Therefore, good spreading of ECA towards the substrate surface is essential to promote excellent adhesion properties.

In this research project, multi-walled carbon nanotubes (MWCNT) is used as a conductive filler in ECA composites to study effect of MWCNT filler loading on ECA electrical performance, and to study the effect of substrate surface conditions on mechanical performance of ECA with varying MWCNT filler loading.