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

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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 conducive 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 kebolehbasahan 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 elektrikal ECA. Stylus profilometer digunakan bagi mengukur kekasaran permukaan dan ujian sudut sentuhan dijalankan bagi menguji kebolehbasahan 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 kebolehbasahan 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 kebolehbasahan 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 kebolehbasahan 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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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 - Isotopically 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, $\mathrm{W/(m.K)}$

phr - Parts per hundred

Ra - Surface roughness, μm

γ_{SG} - Free energy per unit area of solid-gas, $\mathrm{mJ/m^2}$

γ_{LG} - Free energy per unit area of liquid-gas, $\mathrm{mJ/m^2}$

γ_{SL} - Free energy per unit area of solid-liquid, $\mathrm{mJ/m^2}$

dA - Area covered by the liquid, $\mathrm{m^2}$

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, $V1 + V_{\text{Distilled Water}}$

Vm - Matrix volume fraction

Vf - Filler volume fraction

R_s - Sheet resistance $(\frac{\Omega}{\mathrm{sq}})$

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 isotopically 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.