The effect of substrate surface conditions on mechanical performance of electrically conductive adhesive

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ABSTRACT – This project investigates the effect of surface treatment towards the surface roughness and surface wettability which contributed to the lap shear strength of electrically conductive adhesive (ECA) bonded to aluminum-aluminum substrate. Several surface treatment methods were applied on the aluminum substrate which involved chemical etching process with the utilization of NaOH solution and HCl solution, and mechanical abrasion process by SiC abrasive paper G180 and G1200. Four-point probe test on ECA sheet resistance shows that the increase of multi-walled carbon nanotube (MWCNT) filler loading decreased the ECA electrical resistivity. As chemically etched substrate provides highest surface roughness and the lowest contact angle, the ECA bonded to the substrate exhibit the highest shear strength when subjected to lap shear test.

1. INTRODUCTION

Nowadays, with increasing the 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 [1]. As interconnect materials, the mechanical strength of ECA is another aspect to be improvised in addition to the electrical conductive performance. The adhesion performance is influenced by the surface wetting properties which play an important role to improve ECA bonded joint mechanical strength. The strong bonded joint requires adequate intimate contact with the substrate for generating strong physical and chemical bonds.

ECA being a type of polymer based composite materials exhibit poor surface properties to attain good adhesion as the material is inherently inert in nature. The surface properties of substrate shall be enhanced by increasing the surface roughness or by modifying the surface chemistry of the substrate via surface treatment methods [2].

The aim of this research is to study the effect of substrate surface conditions on mechanical strength of ECA bonded joint since there is only limited research found in the literature.

2. RESEARCH METHODOLOGY

In this study, ECA with MWCNT filler loading of 5 wt.%, 6 wt.% and 7 wt.% were prepared and characterized in terms of their conductivity performance by determining the ECA sheet resistance using JANDEL In-Line Four Point Probes. The test was conducted with referring to ASTM F390. Different surface treatment methods were applied on aluminum substrate which are grinding with SiC abrasive paper G180, polishing with SiC abrasive paper G1200 and chemical etching.

The surface roughness, Ra, of as-received and treated surface of aluminum substrate were determined by using stylus profilometer brand Mitutoyo SJ-410. The contact angle measurement on as-received and treated surface of aluminum substrate were carried out to determine the wettability of liquid toward the different substrate surface conditions, with reference to the ASTM D5725. Lap shear test were applied on ECA with varying MWCNT filler loading and different substrate surface conditions, in accordance with ASTM D1002. Morphological study using a Scanning Electron Microscopy (SEM) was carried out to understand the failure behavior of ECA following lap shear test.

3. RESULTS AND DISCUSSION

3.1 Sheet resistance

Figure 3.1 depicts that the sheet resistance decreased with an increase in the MWCNT filler loading from 5 wt.% to 7 wt.%, due to an increase the contact between MWCNT particles and enhancement formation of three-dimensional network [3].

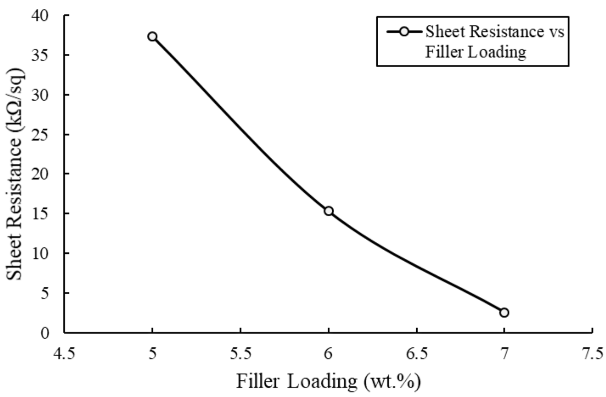


Figure 3.1 Graph of sheet resistance per unit area against percentage of MWCNT filler loading

3.2 Surface roughness

Surface roughness measurement on as-received and surface-treated aluminum substrates as given in Table 3.1 show that the chemically etched substrate exhibits the highest surface roughness while polishing with SiC abrasive paper G1200 yield in the lowest surface roughness.

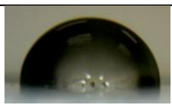
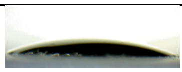
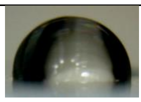
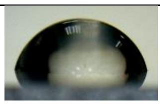
Table 3.1 Surface roughness of different substrate surface conditions

Surface Treatment	Surface Roughness, Ra (µm)
As-Received	0.36 ± 0.02
Chemical Etching	2.60 ± 0.30
Grinding with SiC Abrasive Paper G180	0.52 ± 0.05
Polishing with SiC Abrasive Paper G1200	0.10 ± 0.01

3.3 Contact angle

Based on the results from contact angle measurement in Table 3.2, the chemically etched substrate has the lowest contact angle, which indicates an excellent surface wettability since higher surface roughness promote better spreading of liquid to the substrate surface [4]. Besides, the grinded substrate with SiC abrasive paper G180 yield in the highest contact angle, an indication of poor surface wettability.

Table 3.2 Water droplet contact angle on different substrate surface conditions

Surface Treatment	Water Droplet Behavior	Contact Angle (°) (θ)
As-Received		74.47 ± 5.29
Chemical Etching		16.78 ± 4.40
Grinding with SiC Abrasive Paper G180		85.66 ± 6.42
Polishing with SiC Abrasive Paper G1200		68.52 ± 3.17

3.4 Lap shear test

Based on Figure 3.2, the highest shear strength is found for ECA with filler loading of 6 wt.% bonded to chemically etched substrate, which provide the highest surface roughness therefore enhancing the mechanical interlocking of the bonded joint. Meanwhile, ECA with 7 wt.% filler loading exhibit the lowest shear strength as compared to ECA with 5 wt.% and 6 wt.% filler loading when bonded to all surface conditions, possibly due to agglomeration of MWCNT in the composites, which results in poorer mechanical properties [5].

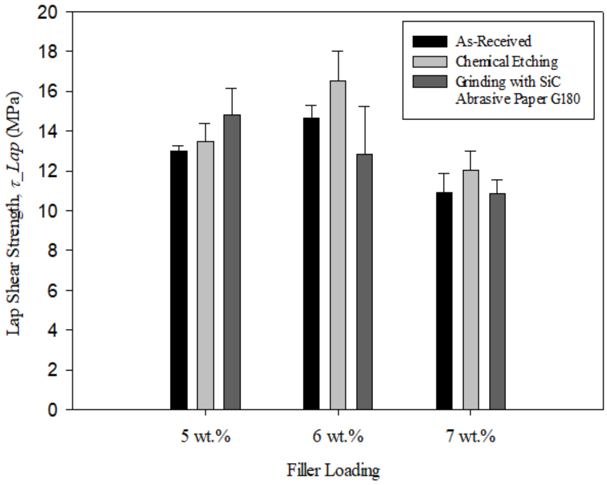


Figure 3.2 Graph of lap shear strength of ECA against MWCNT filler loading

4. SUMMARY

The ECA with 7 wt.% filler loading exhibit an excellent electrical conductivity performance. In addition, shear strength of ECA is strongest when bonded to the chemically etched substrate, as the substrate has the lowest contact angle and highest surface roughness.

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REFERENCES

[1] C. C. Sean, S. Pamornpol, O. H. Keat, and R. Durairaj, "Mechanical and Electrical Properties of Carbon Nanotubes Based Isotropic Conductive Adhesives," vol. 857, pp. 93–97, 2016.

[2] H. M. S. Iqbal, S. Bhowmik, and R. Benedictus, "Study on the effect of surface morphology on adhesion properties of polybenzimidazole adhesive bonded composite joints," *Int. J. Adhes. Adhes.*, vol. 72, no. October 2016, pp. 43–50, 2017.

[3] L. Yi, L. Daniel, and W. C.P., *Electrical Conductive Adhesives with Nanotechnologies*. New York: Springer Science+Business Media, 2010.

[4] K. Leena, K. K. Athira, S. Bhuvaneswari, S. Suraj, and V. L. Rao, "Effect of surface pre-treatment on surface characteristics and adhesive bond strength of aluminium alloy," *Int. J. Adhes. Adhes.*, vol. 70, pp. 265–270, 2016.

[5] J. Trinidad, L. Chen, A. Lian, and B. Zhao, "Solvent presence and its impact on the lap-shear strength of SDS-decorated graphene hybrid electrically conductive adhesives," *Int. J. Adhes. Adhes.*, vol. 78, no. May, pp. 102–110, 2017.