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The Effect of Carbon Nanotube Loading on Wettability of Solder Paste SAC 237 and Different Substrates

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***Abstract*— Wettability of Pb-free soldered surface is one of the main solderability classifications. The aim of this study is to investigate the effect of various percentages of carbon nanotube (CNT) loading (0 – 4%) on the wettability of solder paste SAC 237 and different substrates namely copper (Cu) and tin (Sn). The influence of surface roughness on the wetting behaviour was also studied. Both substrates were undergone a mechanical abrasion process by using four different grit sizes (P240 , P400, P600 and P800) before performing the reflow soldering process using a reflow oven at a temperature of 180°C for 13 minutes. The surface roughness of the substrates was characterized by using a profilometer. Meanwhile, wettability tests were performed by using the optical microscope. Both substrates have shown similar behaviour; the rougher surface gives better wettability compared to the smoother one. The wettability of SAC 237 is not significantly affected by the addition of various percentages of CNT. However, CNT loading in the solder paste has shown the different wetting behaviour for both substrates.**

***Keywords*— reflow soldering; wettability; carbon nanotube; surface roughness**

I. Introduction

Efforts to finding a suitable application for carbon nanotubes (CNTs) over the past decades have never-ending. Their amazing properties [1] specifically electrical, thermal, mechanical, and electrochemical make this material have many potential uses such as field emission devices [2], electronic circuits, devices, and interconnects [3], nanoscale sensors [4], and electronic packaging including as fillers for composites. There are several factors influenced the effectiveness of CNTs in the interconnected application. This includes the density of CNTs in the area and a good wetting in the alloy matrix[5]. Nai et. al. reported that it is possible to increase the mechanical and thermal properties of soldered sample by using CNT without affecting the electrical properties [6]. However, researchers more focused on the SAC 305 solder paste in the literature.

In the electronic industries, products repair becomes more challenging and expensive when defects occur at downstream of the production line. Non-wetting or poor wetting is a very critical defect as it is difficult to identify and can cause a serious claim after products are delivered to the market. Some electronic devices are used in an unstable environment where the humidity and temperature keep changing. Electronic devices are also used in a continuous vibration or shocks environment.

In the soldering practice, a metallurgical bond is formed between the molten solder and a metal surface. Consequently, the ability of the molten solders to flow or spread on the metal is essential for the development of a strong metallurgical bond. The phenomenon of fluid spreading on a surface is also referred to wetting. Wetting is also denoted to the ability of molten solder to react with a substrate to form a certain amount of intermetallic compound (IMC) at the interface of solder and substrate. The IMC will act as an adhesion layer to connect the solder and substrate [7]. The inadequate strength of the solder joints will lead to cracks on solder joint, hence, damage the electronic components [8]. Thus, the wettability of the solder paste alloy is often given the highest priority compared to the other key features required, such as printability, tack time, etc.

The essential precondition for a good wettability is that the molten solder wets the surface of the substrate as completely as possible and that the latter has sufficient pores and hollows and permits the wetting. This is possible, using special treatment of the substrate; i.e. mechanical abrasion, to enlarge the contact surface; or by varying the composition of the solder used. The surface roughness of the substrate is well-thought-out one of the significant features that influence wetting and spreading characteristics of molten solder flowing over it [9]. However, limited literature data is available on how it influences wetting. Thus, current research aims at understanding the effects of various percentages of CNT loading into the solder paste SAC 237 on the wettability of the solder and two different substrates i.e. Cu and Sn. Another objective was to investigate the effect of surface roughness of a substrate on the wetting behaviour.

II. METHODOLOGY

A. Materials

The solder paste SAC 237 (Sn 99.9%, Ag 0.3%, Cu 0.7%) with different percentage of CNT (1% - 4%) were supplied by RedRing Solder (M) Sdn. Bhd. Cu and Sn plates were supplied by Electronic Packaging Research Society (EPRS), Universiti Kebangsaan Malaysia.

B. Preparation of Substrate

The Cu and Sn substrates were cut into a dimension of 15 mm x 50 mm x 0.3 mm. The substrates were undergone a mechanical abrasion process to give a micro roughness on its surface. This process was performed by using a polishing machine with a speed of 300 rpm and four different grit sizes i.e. P240, P400, P600 and P800. The substrate surface was then cleaned by using acetone. The surface roughness of the substrates was characterized by using an Infinite Focus Microscope (IFM) profilometer.

C. Reflow Soldering

A stencil printing was used to apply the solder paste on the substrate surface. A straight pattern solder was made at the centre of the substrate surface. The solder paste with and without CNT were applied on the substrate. All substrates were soldered using a reflow oven at a temperature of 315°C in 15 minutes. Then the soldered samples were cooled to ambient temperature.

D. Contact Angle Measurement

The soldered samples were placed in a cold mounting mold and then, the resin was poured into the mold. After the resin had been set, the samples were grinded by using abrasive paper to get a cross section of the soldered samples. The determination of contact angle on the substrate surfaces with different surface roughness were performed by using an optical microscope. The contact angles were measured at the both left and right sides. Ten soldered specimens were measured to obtain the average of 20 readings for each sample. A standard deviation between measurements less than 3% was the higher limit to accept the value.

Contact angles are closely associated to wettability. A molten solder alloy will wet a solid substrate when its surface energy is lower than the substrate surface energy. A smaller contact angle indicates that more of the molten solder alloy spreads over an area for a given liquid volume; therefore, the molten solder alloy has a high wettability on that surface. Large contact angles are related to poor wettability.

III. RESULTS AND DISCUSSION

A. Surface Roughness

Fig. 1 shows the effect of abrasion process using different silicon carbide grit sizes on the surface roughness of Sn and Cu substrates. It is clearly showed that the roughness of the substrate surface decreases as the number of grit size increases. This means P240 gives the roughest surface, and P800 contributes to the smoothest surface. In the comparison of both substrates, Sn substrate shows the higher value of surface roughness. This might be due to the hardness value of the substrate that can be referred in the Table I. Possess a softer surface makes the Sn substrate easier to be abraded. This influenced the wetting properties of the solder that is illustrated in the Fig. 2 and Fig. 3.

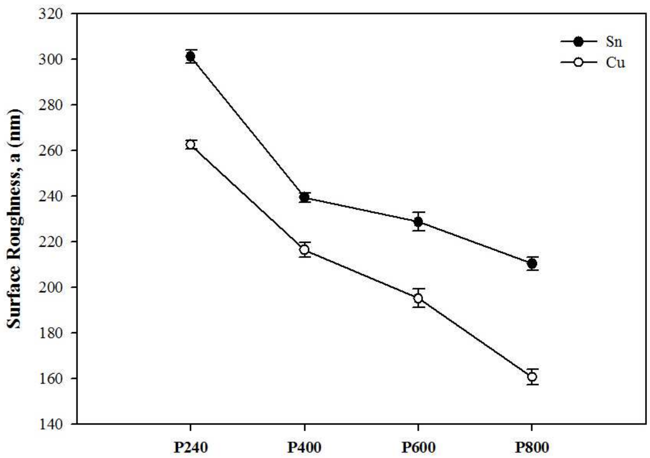

Fig. 1. The effect of grit size of abrasive paper on the surface roughness of Sn and Cu substrates

TABLE I
COMPARISON OF HARDNESS VALUE OF TIN AND COPPER [10]

Substrate	Mohs hardness	Brinell hardness (MPa)
Cu	3.0000	235–878
Sn	1.5000	51-75

B. Wettability

Fig. 2 shows the cross-sectional images of the soldered samples on Cu and Sn substrate without CNT addition. As the number of grit size increases, the contact angle is also increased. That means the wettability of the molten solder decreases as the surface roughness value decreased. This might be correlated with the mechanical interlocking mechanism between the molten solder and substrate surface. This mechanism explained that the proper adhesion occurs when the liquid penetrates into pores, holes, crevices and other distortion of the substrate and lock mechanically to the substrate. That means a good wetting occurs when the molten solder flows into each micro-grooves or micro-pores on the substrate surface. Therefore, the number of peaks and micro-pores affect the flow of the molten solder on the substrate surface. The more microgrooves or micropore, the more the surface area of the substrates in contact with molten solder causes the more solder flowing down and enters into the micro-grooves or micro-pores. This wetting phenomenon enhances the adhesion between substrate and solder, in turn affect the strength and durability of the solder joint.

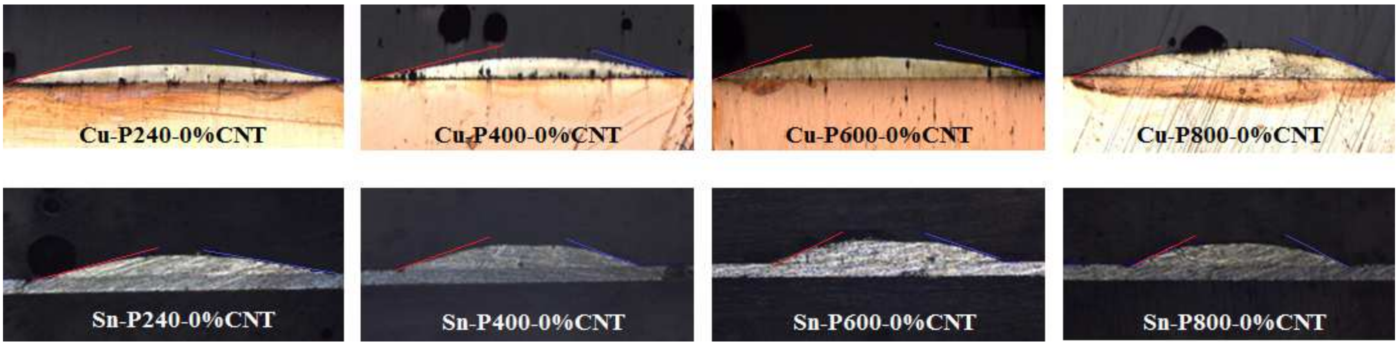

Fig. 2. Micrographs of a cross section of the soldered samples on Cu and Sn substrates without CNT addition (50X).

Moreover, the wetting area or spreading area of the molten solder was enlarged as the surface roughness increased (lower grit size). This phenomenon is illustrated in Fig. 3. Wenzel [11] stated that the rough surface has greater interface area causes the higher surface energy and consequently decrease the contact angle.

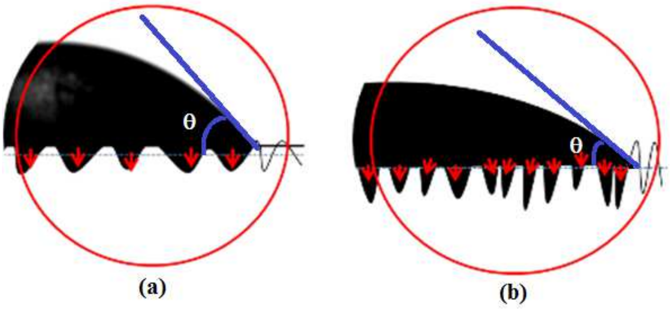

Fig. 3. Mechanism of mechanical interlocking between SAC237 and substrate; (a) smoother surface and (b) rougher surface.

In both cases (Cu and Sn substrates), the smaller spreading area results in a larger contact angle consequently reduced the wettability. However, the greater the spreading area lead to lower the contact angle. Thus, wettability became more excellent. This argument is in agreement with the result of contact angle and spreading area reported by Noor et al. [12].

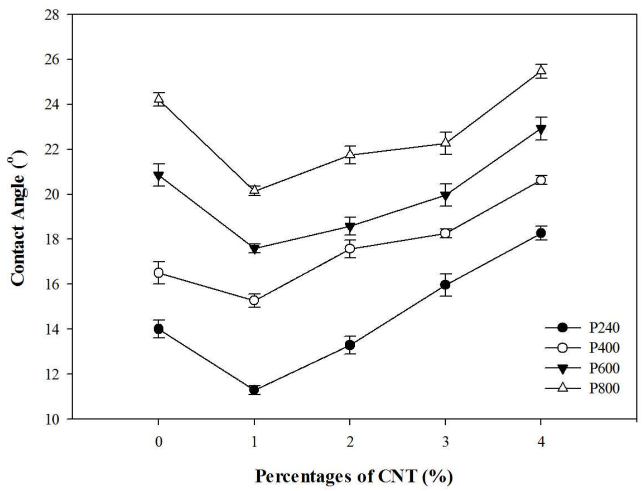

Fig. 4. The effect of different percentages of CNT loading on wettability of SAC 237 and Cu substrates

Fig. 4 shows the effect of different percentages of CNT loading on the wettability of SAC 237 and Cu substrate. From the figure, it was found that after adding 1% of CNT, the contact angle between the surface of the Cu substrate and solder decreases compared to the one without CNT. However, when the amount of CNT increases the contact angle was also found increased. This might be due to the increase in viscosity of the molten solder. Tian et al. [13] reported that with increasing viscosity, the shear strength of the solder joints decreases.

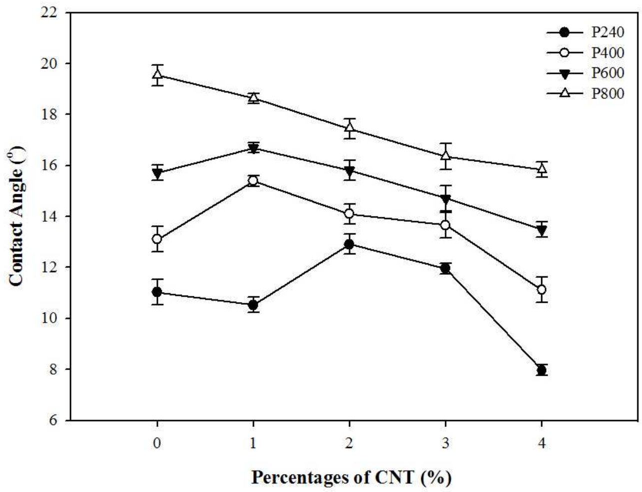

Fig. 5. The effect of different percentages of CNT loading on wettability of SAC 237 and Sn substrates

Fig. 5 indicates the effect of different percentages of CNT loading on the wettability of SAC 237 and Sn substrate. It was found that the contact angle between the tin substrate and solder shows the different pattern or trend compared to the Cu substrate. It is obviously shown that there is a significant effect of adding CNT on the wettability of the solder and tin substrate where 4% CNT has the lowest contact angle. In terms of the impact of different substrates, it was found that the contact angle between solder paste SAC237 and Cu substrate is higher than the tin substrate. This indicates that the wettability of solder paste SAC 237 and Cu substrate is lower than the tin substrate. This might be attributed to the Cu substrate has lower surface energy. The adhesion force between the liquid and the substrates surface are influenced by the surface energy of the substrates where the attraction between molecules of liquids and substrates become stronger when the surface energy is higher. As a result, lower the contact angle between solder and substrates. In contrast, the lower surface energy caused the weak attraction between molecules of solder alloy and substrates growing increasingly, resulting in a higher contact angle [14]. In other words, the higher wettability would give the stronger metallurgical bonding between the tin substrate and SAC 237 with CNT than the solder without CNT.

IV. Conclusions

The surface roughness significantly influences the wetting behaviour. The rougher surface of the substrate resulting in the lower contact angle, hence better wettability compared to the smoother surface. Meanwhile, the wettability of solder paste SAC 237 is significantly improved by the addition of various percentages of a carbon nanotube, especially for the tin substrate. However, for Cu substrate, it assumes its best properties in the smallest carbon nanotube addition, not exceeding 1%. A larger amount of CNT in the solder paste had an adverse influence on its wettability on Cu.

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