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Effect of Fluxes on 60Sn-40Bi Solder Alloy on Copper Substrate

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Abstract. This paper investigated the effect of different types of fluxes on the wettability of a type of low temperature lead-free solder, 60Sn-40Bi alloy. The purpose of this paper is to investigate the effect of different types of fluxes on the wettability of 60Sn-40Bi solder (T_m : 138 -170 ^oC), so that the most compatible flux to be used with low temperature alloy can be determined.The results of this paper showed that the water soluble flux sample has the highest spread area and lowest contact angle. This meant that the solder has the highest wettability when water soluble flux is used, followed by RMA flux and low solids flux. Therefore, it was determined that water soluble flux is the most compatible to be used with the low temperature 60Sn-40Bi solder. The characteristic of this type of flux enables it to function well even at a low working temperature.

1. Introduction

Flux is a very important part of soldering as it is needed to prevent oxides forming when hot metals are put into contact with air (Dongkai, 2005; Alvin, 1989). In the electronic manufacturing industry, many types of flux are currently being used in the assembly process. However, the decision to choose which type of flux to be used depends on the product's end use environment (Dongkai, 2005). Some products require that its printed circuit board (PCB) have low flux residues while some may need it to be able to withstand high working temperature. Therefore, the type of flux chosen must satisfy the required conditions or else the end product may be defective (Ervina & Amares, 2015).

Nowadays, there are various types of flux used in soldering which is a major part of the electronic manufacturing process, namely water soluble flux, rosin mildly activated flux (RMA) and RMA/low solids flux (Dongkai, 2005; Giles and David, 2004). Sometimes, it is a problem for manufacturers to choose the most suitable type of flux to be used in a certain process as each type of flux inhibits different characteristic and caters to different needs. If the wrong type of flux is used, the soldered PCB might have defects and this will directly affect the performance of the electronic products.

Other than that, the wettability of the solder is also a main consideration (Ervina and Amares, 2012). Wettability is the ability of a solid surface to reduce the surface tension of a liquid in contact with it such that it can spread over the solid surface and wet it (Ervina et. al, 2008). In this case, the solid surface is the PCB board that is about to be soldered while the liquid is the molten solder. The wettability of a solder is dependent on the type of flux used thus it is important to use the suitable type of flux during a soldering process.

Previously in the soldering process, there are two types of solder used: Sn-Pb (Tin-Lead) solder or SAC (Tin-Silver-Copper) solder. For eutectic SAC solder, the melting point is 223^{o}C (Ervina & Faziera, 2016) while for eutectic Sn-Pb solders the melting point is 183^{o}C. At these temperatures, the fluxes are compatible with the solder and are able to work well. However, recently there are various types of low temperature solders being used in the industry which has melting points below 180^{o}C. The main concern of the industry is whether the existing fluxes are compatible to be used with the low temperature solders or not. In this paper, testing will be done to study the effect of different types of fluxes on the wettability of 60Sn-40Bi solder, which is a type of low temperature solder.

2. Materials and Methods

(A) Preparation of Solder in Required Composition

Tin (Sn) of 6g and bismuth (Bi) of 4g were weighed using an electronic balance. Both types of metals were put into a crucible which was then placed on the hot plate. After that, the hot plate was switched on and the temperature inside the crucible was measured using a multimeter. The crucible was heated to a temperature of 271^{o}C where both metals melted and mixed together (T_m tin: 232^{o}C and T_m bismuth: 271^{o}C). After both metals have mixed together, the hot plate was then switched off and the crucible was allowed to cool down so that the alloy can solidify. Next, the hot plate was switched on again and the crucible was heated to a temperature of 170^{o}C so that the alloy becomes molten form again(Tm of 60Sn-40Bi alloy: 138 -170^{o}C). After the alloy has become molten, the hot plate was then switched off and the alloy was allowed to cool down and solidify. The heating and cooling process were repeated two more times to ensure that the mixture of alloy is homogenous throughout the crucible. Next, the alloy was heated one more time to a temperature of 170^{o}C where it became molten form and immediately it was poured out onto a pot pedestal. After the solder has cool down and solidified, it was removed from the pot pedestal. The solid solder was then flattened to a uniform thickness of 1mm using a hydraulic hot molding machine. Using a puncher, the solder was punched into multiple billets of 7mm diameter.

(B) Applying Flux and Melting the Samples onto Copper Sheets

Prior to the experiment, multiple copper sheets of size 15 x 15mm were prepared. The billets from Part (A) were taken to be used here. A total of nine billets were needed, three billets for each type of flux. Using a cotton bud, the RMA flux were applied on the top and bottom surface of three billets. Each billet was then placed on the center of a copper sheet. After that, the hot plate was switched on again and heated until it reached a temperature of 150^{o}C. Using a tweezers, the copper plate containing the billet were placed on top of the hot plate for 10 seconds and then removed from the hot plate. These 10 seconds are the reflow time for the chemical reaction between the solder, flux and copper sheet to occur. For a consistent result, the reflow time should be the same for all samples. The previous steps were repeated twice but using a reflow temperature of 160^{o}C and 170^{o}C instead. After that, the same steps were repeated again by using the other two types of flux: low solids flux and water soluble flux. All samples were left to be cooled down. Before moving on to Part (C), the spread area of the solder on the copper plates for all samples were observed and recorded for comparison and analysis.

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(C) Mounting the Sample and Observing using Optical Microscope

One side of the short PVC pipe was sealed using a cellophane tape with the sticky side facing the inside of the PVC pipe. Then, two small pieces of plasticine were sticks onto two edges of a soldered copper sheet from Part (B), and then the copper sheet was placed inside the PVC pipe. The side with plasticine was faced inside so that it would stick onto the cellophane tape. This is to ensure that the copper sheet will remain straight upright and not be slanted. After that, an epoxy mixture was prepared by mixing resin and hardener with a ratio of 10:1. For each 10ml of resin used, we need to mix in 1ml of hardener. The mixture was stirred until it become homogenous and then it was carefully poured into the PVC pipe containing the copper sheet until it completely fill up the PVC pipe. Care must be taken so that when pouring the epoxy mixture into the pipe, the copper sheet remains straight upright and not be slanted. The previous steps were repeated for all the samples prepared in Part (B). After that, all the samples were left to be hardened for one day. Each PVC pipe was labeled for easy identification later on. On the next day, each pieces of PVC pipe was cut about halfway through the length of the pipe. The cut surface was then polished until the surface is flat, clean and shiny so that the contact angle can be clearly observed under the microscope. Each sample was put under the microscope, and the contact angles between the solder and the copper sheet were measured for each sample. For each sample, there are two contact angles, one on the left and one on the right. Both angles were measured and the angle with the smaller value was chosen. The contact angles for solder using different type of flux and also different reflux temperatures were recorded and tabulated for analysis.

3. Results and discussions

(a) Spread Area Comparison

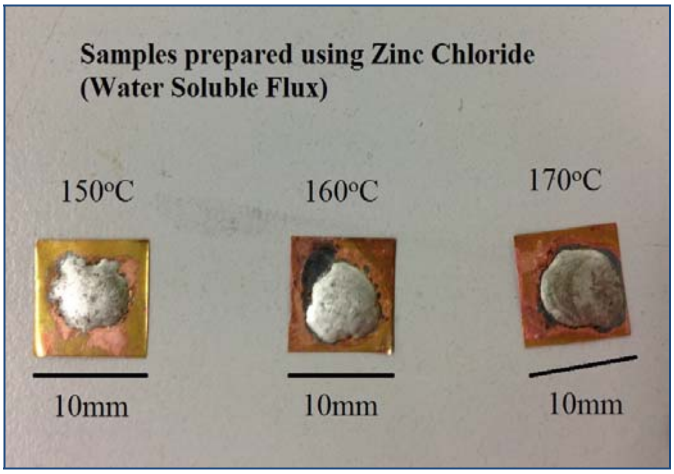

Figure 1: Spread Area for Samples prepared using Water Soluble Flux

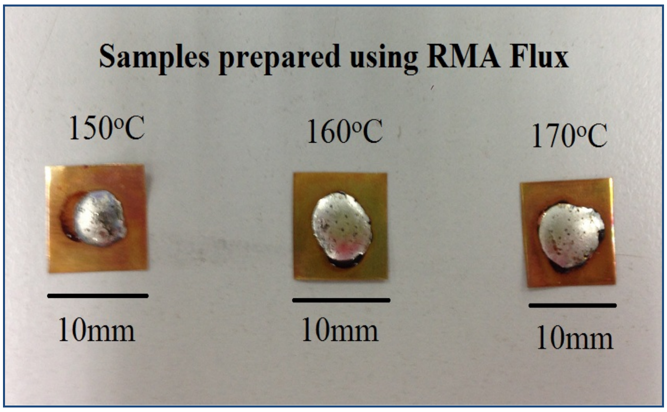

Figure 2: Spread Area for Samples prepared using RMA Flux

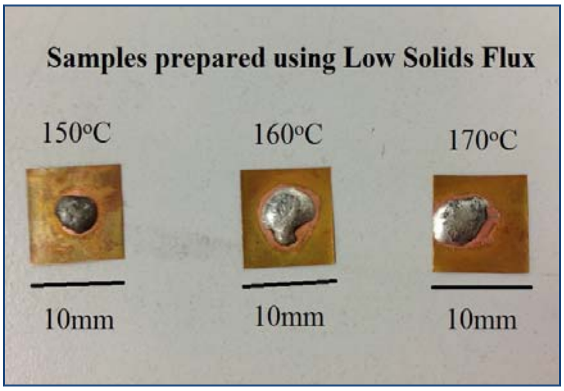

Figure 3: Spread Area for Samples prepared using Low Solids Flux

Figure 1, 2 and 3 show the spread area of the solder for all the samples. By comparing the spread area between samples using different type of flux, the type of flux that provides the most wettability to the solder can be determined. Solder with a higher wettability will be able to spread more easily therefore resulting in a larger spread area. From the figures, it can clearly be seen that the solder that spread the most was from the samples using water soluble flux, followed by samples using RMA flux and finally samples using low solids flux. From this we can deduce that water soluble flux provides the most wettability to the solder. This result is similar to what Lawrence et al. had obtained during their testing on the wetting of Sn-Bi alloys. In their paper, they found that solder of 60Sn-40Bi have a higher spread area when water soluble flux was used during the soldering process instead of a no-clean flux (Lawrence et al., 1993). Besides that, it is also important to note that for each type of flux, the spread area increases when the reflow temperature increases. When the reflow temperature is higher, the flux becomes more reactive and was able to function better in cleaning the copper sheet and providing solder wetting. Therefore, the wettability increases when the reflow temperature is higher which in turn results in a larger spread area.

The contact angles between the copper sheet and the solder could be measured accurately using an optical microscope. Figure 4 to 12 shows the contact angle for all the samples. The result of the contact angle must be an inverse of the spread area, which means that the solder with best wettability have the highest spread area and lowest contact angle (Ervina and Tan, 2013). As mentioned earlier, a solder with a higher wettability will be able to spread across the copper sheet earlier, thus resulting in the high spread area and low contact angle. From Figure 4 to 12, it can be clearly seen that the contact angle is lowest when water soluble flux is used, followed by RMA flux and finally low solids flux. The result shows that for Sn-Bi solder, water soluble flux is the best to be used as it gives the highest wettability to the solder. This is due to the compatibility between the solder and flux. Besides that, the water soluble flux contains a lot of carboxylic acid which acts as activators thus it is very active. Dongkai said that due to this property, the flux is able to perform well and increases solder wetting even at low temperature (Dongkai, 2005).

For each specimen, there are two contact angles (left and right), both angles were recorded and their average was calculated. Then, all the data were tabulated into Table 1 for analysis. After that, a graph of contact angle versus reflow temperature was drawn as shown in Figure 13. From this figure, it can be seen that for samples using water soluble and RMA flux, the contact angle decreases as the reflow temperature increases. This is due to the fact that the higher the reflow temperature, the more reactive the solder becomes thus its wettability increases. A higher wettability will then result in a lower contact angle between the solder and the copper plate. For the samples using low solids flux, the contact angle decreases a lot when the reflow temperature was increased from 150 to 160^{o}C. However, when the reflow temperature was again increased to 170^{o}C, the contact angle does not have any signification reduction. This shows that for low solids flux, the wettability was already optimum at 160^{o}C. Therefore it does not improve anymore even if the reflow temperature was increased. As what Ervina and Tan have found, there exist some cases where the wettability does not improve anymore even if the reflow temperature is increased (Ervina and Tan, 2013).

Table 1: List of Contact Angle

Type of Flux	Reflow Temperature (^{o}C)	Contact Angle (^{o})		
		Left	Right	Average
Water Soluble	150	32.00	41.14	36.57
	160	35.59	24.47	30.03
	170	19.60	15.38	17.49
RMA	150	52.40	47.62	50.01
	160	42.45	34.67	38.56
	170	19.50	21.69	20.595
Low Solids	150	127.63	91.09	109.36
	160	48.40	43.98	46.19
	170	31.77	59.38	45.575

(b) Contact Angle Comparison

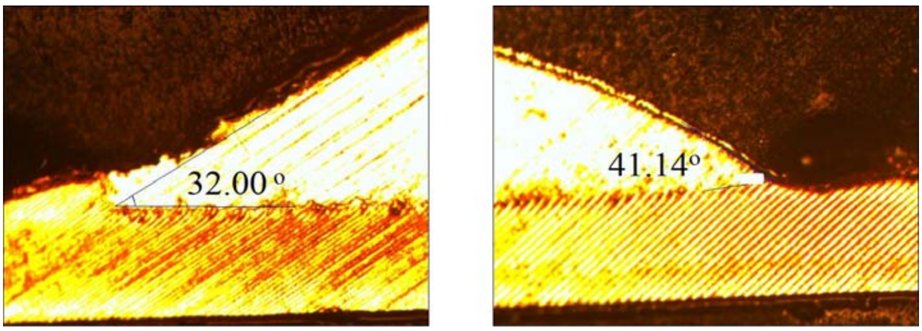

Figure 4: Contact Angle for Solder with Water Soluble Flux (Reflux Temperature: 150 ^{o}C) at 10X magnification

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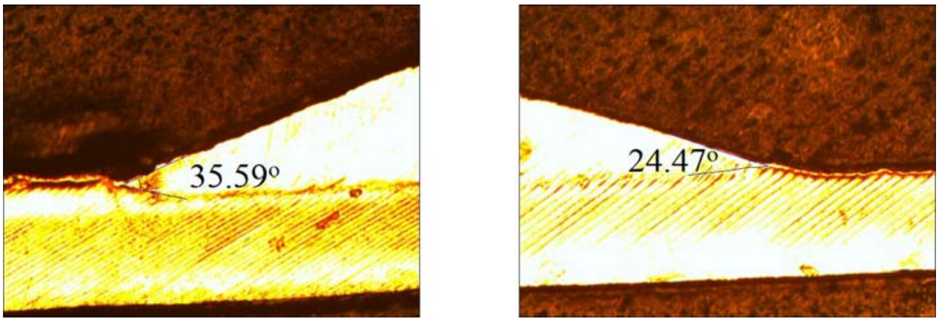

Figure 5: Contact Angle for Solder with Water Soluble Flux (Reflux Temperature: 160 °C) at 10X magnification

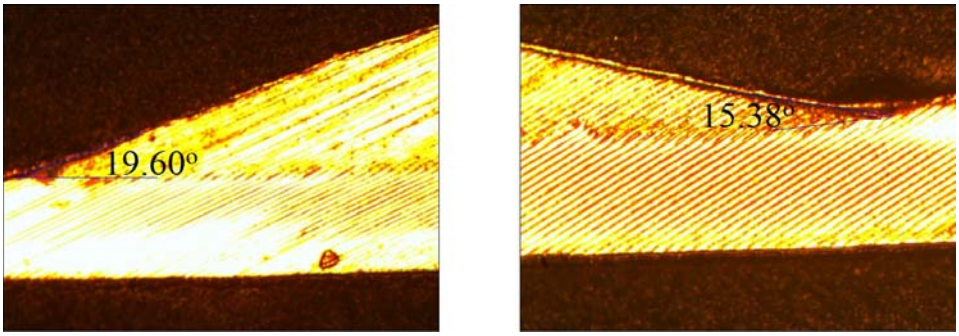

Figure 6: Contact Angle for Solder with Water Soluble Flux (Reflux Temperature: 170 °C) at 10X magnification.

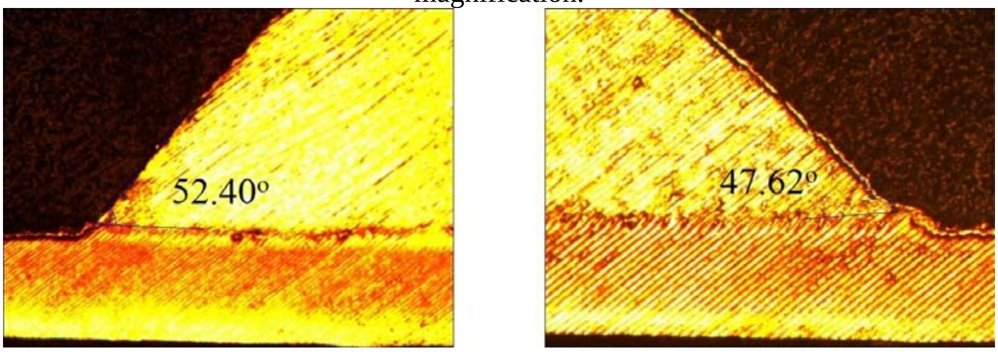

Figure 7: Contact angle for Solder with RMA Flux (Reflux Temperature: 150 °C) at 10X magnification

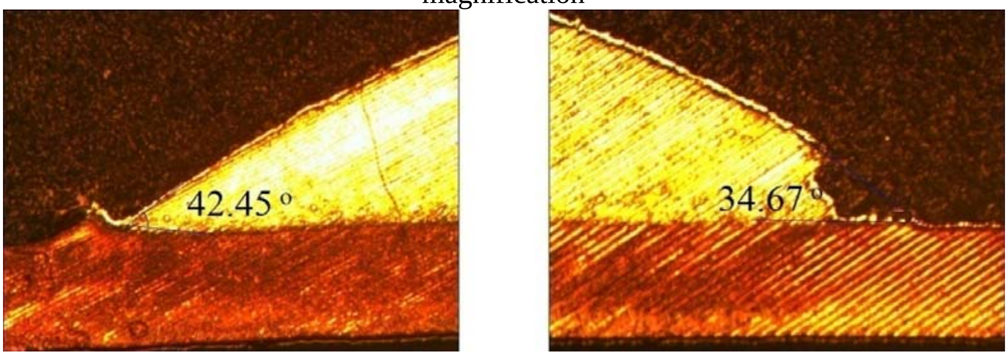

Figure 8: Contact Angle for Solder with RMA Flux (Reflux Temperature: 160 °C) at 10X magnification

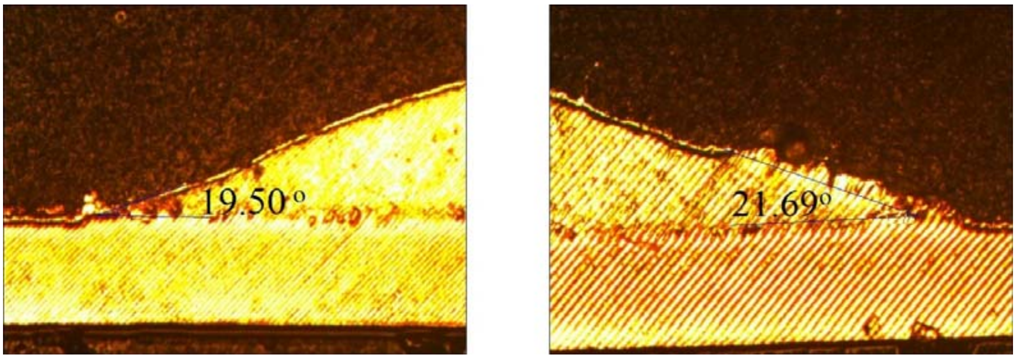

Figure 9: Contact Angle for Solder with RMA Flux (Reflux Temperature: 170°C) at 10X magnification

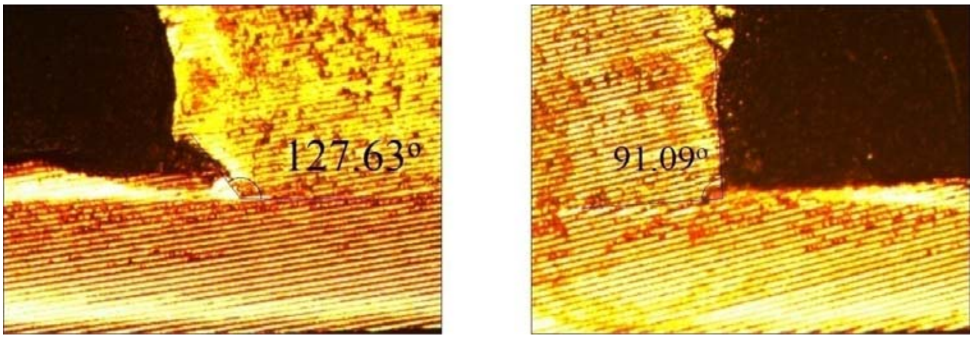

Figure 10: Contact Angle for Solder with Low Solids Flux (Reflux Temperature: 150°C) at 10X magnification

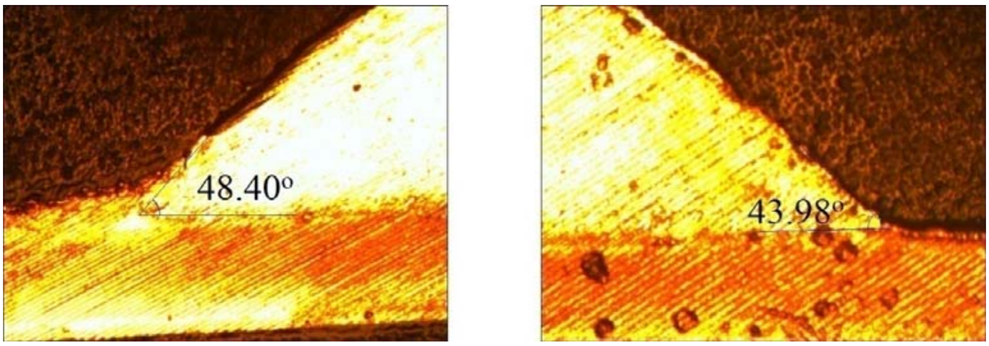

Figure 11: Contact Angle for Solder with Low Solids Flux (Reflux Temperature: 160°C) at 10X magnification

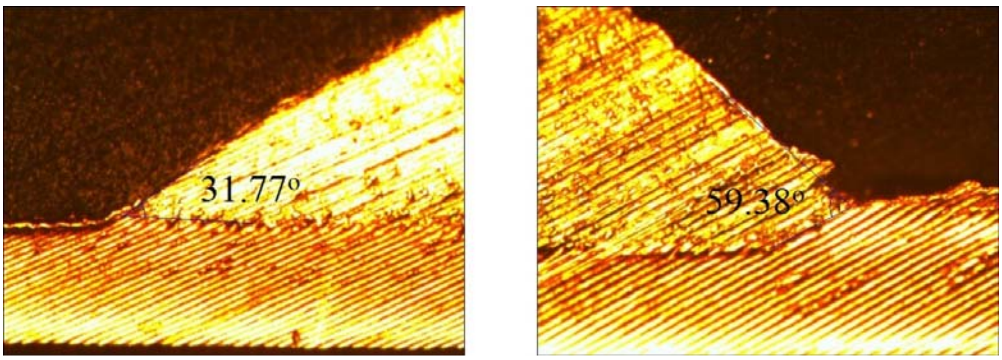

Figure 12: Contact Angle for Solder with Low Solids Flux (Reflux Temperature: 170 °C) at 10X magnification

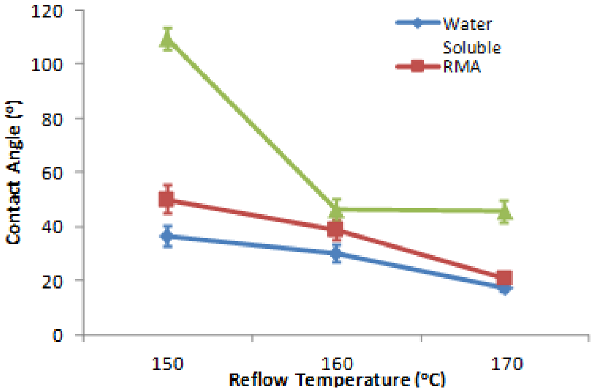

Figure 13: Graph of Contact Angle versus Reflow Temperature for Each Type of Flux

To further study the effect of different fluxes on the solder, a higher magnification image of the interaction at the edge of the solder for water soluble flux and low solids flux were taken. The results are as shown in Figure 14 and 15 below.

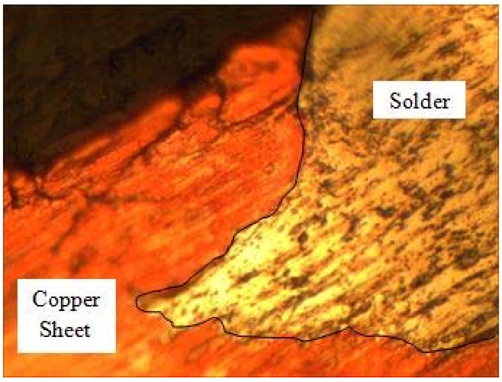

Figure 14: Interaction at the Edge of Solder for Low Solids Flux Sample using Optical Microscope at 50X magnification

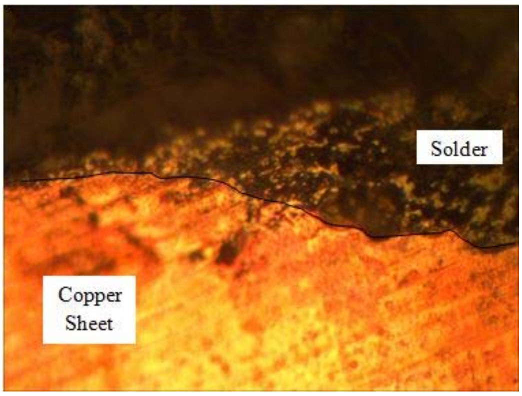

Figure 15: Interaction at the Edge of the Solder for Water Soluble Flux Sample using Optical Microscope at 50X magnification

Figure 14 shows the interaction at the edge of the solder for a low solids flux sample which has a low wettability. The orange part is the copper sheet while the yellowish part is the Sn-Bi solder. From this figure, it can be seen that part of the copper plate is above the solder and blocking its spreading. This is due to the less active low solid flux which was unable to fully dissolve and clean the absorption layer of the copper sheet prior to the soldering process (Mulugeta and Selvaduray, 2000). The absorption and reaction layer of the copper sheet that was not dissolved and cleaned by the flux obstructs the Sn-Bi solder from flowing and therefore resulting in a poor wettability of the solder.

Figure 15 on the other hand, shows the interaction for the high wettability sample using water soluble flux. The orange part in this figure is the copper sheet while the darker brown part is the solder. In this figure, the solder is seen to be able to flow freely as there are no obstructions from the copper sheet. This is because the highly active water soluble flux has fully dissolved and cleaned the absorption and reaction layer of the copper sheet. The only layer left is the pure copper layer which the solder is able to spread over easily thus resulting in a high wettability (Mulugeta and Selvaduray, 2000). The downside of using water soluble flux however is it leaves behind a residue that needs to be cleaned. This is why in Figure 15 the solder appears to be darker as there are residues left on the edge.

4. Conclusions

By comparing and analyzing the results obtained from the wettability test, it was found that the samples soldered using water soluble flux have the highest spread area while the samples soldered using low solids flux have the lowest spread area. Moreover, it was found that at any reflow temperature, the water soluble flux samples yield the lowest contact angles, followed by RMA flux samples and finally the low solids flux samples. For example, at the reflow temperature of 150 C, the water soluble flux sample has a contact angle of 36.57^{o}C and the RMA flux sample has a contact angle of 50.01^{o}C while the low solids flux sample has a contact angle of 109.36^{o}C. Therefore, it can be concluded that the wettability of Sn-Bi solder is highest when it is used with water soluble flux, followed by RMA flux and finally low solids flux. This result also proved that water soluble flux is indeed the most compatible with the low temperature solder used in this experiment which is the Sn-Bi solder. Furthermore, the water soluble flux sample soldered at a reflow temperature of 170^{o}C has the lowest contact angle of 17.49^{o}C. Thus the optimum reflow temperature for water soluble flux was determined to be 170^{o}C.

The results presented in this paper are indeed useful and may contribute a lot to the electronics assembly industry. For any Sn-Bi solders to be used in future assembly lines, the company will be able to decide which type of flux to be used by just referring to this paper. This will directly save a lot of time and cost for the company. However, it is important to take note that the results obtained in this test are only limited to Sn-Bi solders. In a case where another type low temperature solder alloy was to be used, further testing needs to be done to check whether the results still stand true or not.

5. Acknowledgments

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