EXPERIMENTAL STUDY OF SELF-ALIGNMENT DURING REFLOW SOLDERING PROCESS

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ABSTRACT: Self-alignment forces induced by solder reflow are pivotal to many relevant technologies; including precision micro-objects manipulation and chip component assembly especially in high density interconnect PCB. The primary goal of the study is to investigate the self-alignment effect of different lead-free solder experimentally during reflow soldering process. Results show that the self-alignment capability performs at its best in high silver content solder; SAC405 solder followed by SAC305 and SAC105. However the SN100C has almost similar self-alignment capabilities with the SAC305 solder even without silver trace in the SN100C solder alloy. In conclusion, the silver addition in the lead-free SnCu alloy up to 4 % silver increase surface tension of melted solder which contributed to better self-alignment performance. In the case of SN100C, the micro-alloy of Nickel traced in the SnCu alloy improved fluidity of the alloy during the self-alignment process.

KEYWORDS: *Self-Alignment; Reflow Soldering; SAC Solder; Micro Assembly*

1.0 INTRODUCTION

Over many years, surface mount technology demanded the need for miniaturization and lower cost in assembly, especially for higher density package. The trend towards the small size of electronic component leads to the use of the compact size of the chip component. The smallest chip component up to date is 008004 and has the size of 0.25 mm x 0.125 mm. The high integration of smaller size passive discrete chip components in electronic packaging is necessary, especially in many consumer electronic products. At the initial stage of the surface mount assembly process, the solder paste is printed on the copper pad that covered by surface finishes (e.g., ENIG, Imm Ag, Imm Sn). Then, the automated placement machine deposits the surface mount components (SMCs) into the solder paste. The chip components may be shifted from its position during the deposition process. The relative positioning accuracy has become important because the reduction of lead size component may result in a lower relative accuracy of their posts during the deposition process.

Solder self-aligning is one of the interesting physics phenomena during reflow soldering process. The ability to align due to the intrinsic property of surface tension during reflow phase have attracted plenty of researchers to study the phenomenon [1-4]. For example, Kim et al. [1] reported a dynamic self-alignment model for a Flip-chip assembly. In the study, the solder joint has been considered as a viscously damped spring-mass-damper system. The equivalent damping and spring constants represent the equation were calculated. Understanding of self-alignment process has been enhanced by Gao and Zhou [2]. They have proposed a semi-analytical self-alignment force model by utilizing surface minimization approach. A complex phase diagram of the restoring torque for misalignment analysis was obtained. Recent study related to self-alignment of chip components has been reported by Krammer [3]. A numerical model using Surface Evolver has been developed to investigate the restoring force arising and the self-alignment occurring during the reflow process.

Lead-free soldering in the electronics industry in Europe has been implemented since July 1, 2006, according to RoHS legislative [5]. In January 2013 the exempted items such as medical devices and hightech instruments were no longer protected, and all are enforceable under the RoHS2 –European legislation [6]. The Implementation of RoHS-Directive projected huge demand towards lead-free solder. National Electronics Manufacturing Initiative (NEMI) research group originate from the USA recommended Sn-Ag-Cu (SAC) system specifically Sn-3.9 Ag-0.6Cu (SAC396) [5]. Then NEMI has become International Electronics Manufacturing Initiative (iNEMI), and active research on SAC solder has been conducted to narrow down the knowledge gap of the recommended lead-free solder especially SAC solder ball [7-10]. Improved Design Life and Environmentally Aware Manufacturing of Electronics Assemblies (IDEALS), an EU consortium project have recommended near eutectic alloy Sn-3.8Ag-0.7Cu(SAC387) [5]. Soldering Technology Centre (Soldertec) research organization specified a range of compositions Sn-(3.4-4.1)Ag-(0.5-0.9)Cu, and according to their survey on industries, the majority of the company in Europe and Japan are using SAC alloy solder [11]. Japan Electronics and Information Technology Industries Association (JEITA) recommended Sn-2.5 Ag-(0.5-1.0) Cu and Sn-3.0 Ag-0.5 Cu alloy (SAC 305) [12]. The recommendations of the Japanese Association are partly due to promote their patented solder alloy. However, the patent applied by the Senju Metal Industry is protected in Japan only. Other than the recommendation from the various association, latest implementation of RoHS2-directive in Europe is expected to increase the trend of using SAC solder in electronic packaging industry worldwide [6].

However, understanding of lead-free solder joints is still in infancy mode compared to traditional SnPb solders; thus further studies are needed. In this study, the effect of lead-free solder on self-alignment during reflow soldering process is investigated.

2.0 EXPERIMENTAL

In this study, an experiment was carried out to examine the self-alignment effect of chip components. Self-alignment of component type 0603 was selected for the study. All chip components have U-shaped sidewall metallization. An FR4 glass-epoxy test board with a series of copper pads arrangement was used for validation. For soldering the components, Sn1.0Ag0.5Cu (SAC105), Sn3.0Ag0.5Cu

(SAC305), Sn4.0Ag0.5Cu (SAC405) and Sn0.6Cu0.05Ni (SN100C) solder paste were used. For the soldering, reflow soldering profile was set according to JEDEC JSTD-020D standard [13]. The temperature setting for the SAC solder material was limited to a peak temperature of 250°C. At the reflow section, the temperature ramp-up rate and ramp down rate used were less than 2.5 and 3 °C/sec, respectively. The specific reflow temperature and duration setting of each depicted in Figure 1. The setting was selected based on the previous investigation conducted on the desktop reflow oven [14].

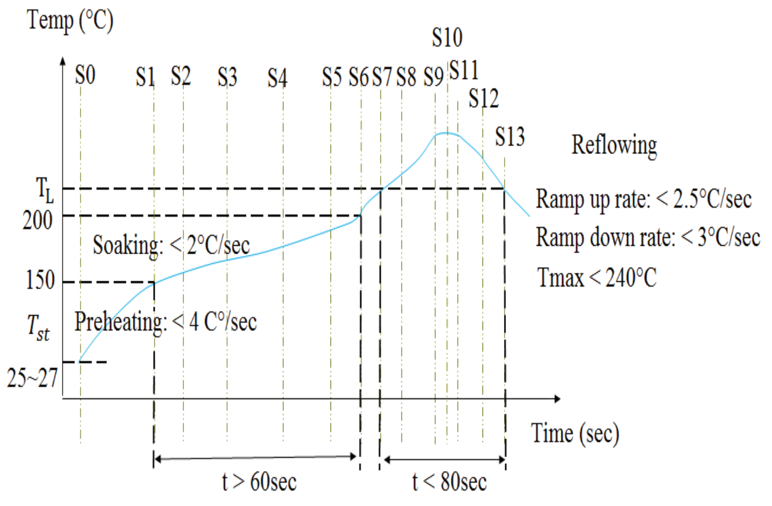

Figure 1: Setting of the reflow profile for the desktop reflow oven

The solder paste was deposited with 100 μm thick; laser cut stainless steel stencil. The area ratio of more than 0.66 was used for the stencil design, as recommended by IPC standard for acceptable solder paste release [15]. According to the norm, when the ratio of the area of the aperture is greater than 0.66 of the inside aperture wall area, a complete solder paste transfer will occur. The aperture size is smaller to the board land size to reduce the chance for solder paste to be printed off the land.

The distance of self-alignment of the components was determined by measuring the position of the chip before and after soldering based on the guidelines of the IPC-9850 standard [16]. The images of the chips were captured with optical microscope device. In order to reduce the time of measuring effort using the device, only the image is captured. Determination of the exact position of the resistors is conducted later using image processing software (Scion Image-Release Alpha 4.0.3.2). The resolution of the acquired image was up to 1.78 μm/pixel. Measurement is performed on both diagonal corner side, and the misalignment offset is calculated. Chip resistors were investigated at various positional offset in the range of 0 to a maximum of 300 μm in both cases of lateral and horizontal direction.

3.0 RESULTS AND DISCUSSION

This study limits the range of positional offset up to 7.5 times the value of a typical accuracy of a high precision placement machine [17]. Figure 2 depicts an example of the misplaced 0603 chip resistors in a y-direction (horizontal) as well as X-direction (lateral). The positions of the chip components after reflow soldering are illustrated on the right side of the picture.

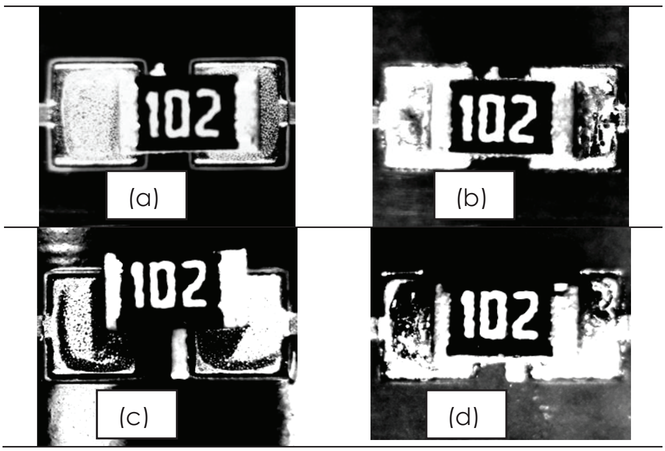

Figure 2: (a) Misplaced 0603 resistor in y-direction, (b) Misplaced 0603 resistor in x-direction, (c) Post-reflow position of y-offset and (d) Post-reflow position of x-offset

Taking IPC-A-610E [18] as a reference, visual inspection of joint quality can be investigated for all the self-aligned resistors in the study. Figure 3 shows an example of visual inspection and measurement of a resistor. From the experiment, it shows that offset (0-300 μm) of the 0603 size components resulted to component alignment in accordance to the standard IPC-A-610E where all the final chip position were on the land of the copper pad after the reflow soldering.

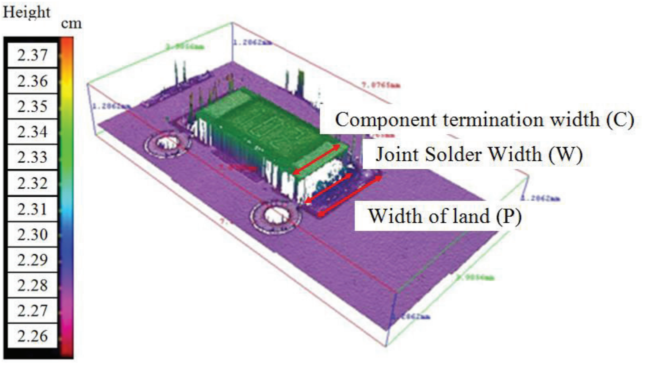

Figure 3: Example of visual inspection of self-alignment in accordance to IPC-A-610E

The offset error of chip component yielded variation of self-alignment during reflow soldering. Therefore, the self-alignment effect of the selected lead-free solder on the chip component was further investigated. The distance traveled of the chip component due to the self-alignment phenomena was observed at various positional offset starting from a range of 50 um to 300 um.

As depicted in Figure 4, the offset travel resulted from self-alignment phenomena in component lengthwise direction was shorter than component width direction. The results revealed that the component offset direction was affecting the surface tension of the molten solder during the reflow process. During self-alignment, the molten solder interacts with air molecules. The melted solder molecules are experiencing stronger cohesion forces with other solder molecules within the domain compared to the air molecules at the interface. It minimized the surface of melted solder as much as possible and adheres to the end of chip component end termination (end side smaller side area) as well as on the surface of the coated copper pad, thus resulting forces acting on the component towards the center. The molten solder near the end of chip created pressure forces arising from surface tension on the side area of the chip component. As the chip travel in a lengthwise direction, the pressure force acting on opposite chip end area yielding lower distance traveled. In comparison to the chip component positional offset in X-direction, the solder adheres to the sidewall was minimal, thus yield lower opposing force acting during self-alignment. The result concluded was consistent with a study by Krammer [3].

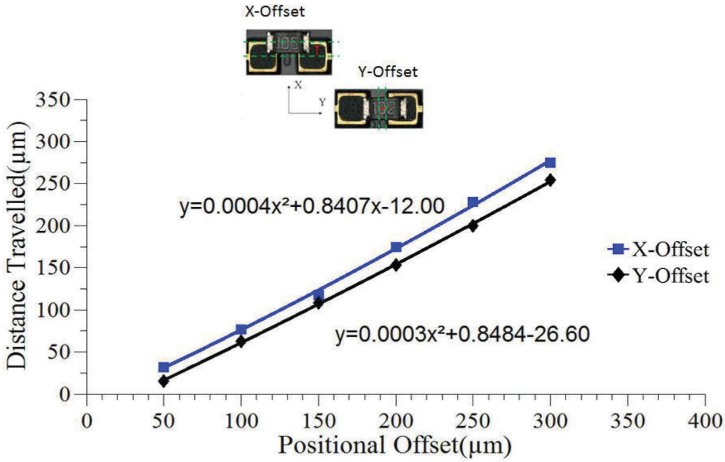

Figure 4: Plot of distance travelled vs. position offset in x-direction (X-Offset) and y-direction (Y-Offset)

A similar phenomenon was visualized for the self-alignment investigation using lead-free solder with different silver content as depicted in Figure 5 and Figure 6. For all silver content in the X-Ag SnCu alloy, the self-alignment capabilities in a lateral direction of chip component were less for a similar offset value. Surface tensions of molten solder during reflow soldering was found as a main contributing factor to the self-alignment of the chip component. At different material composition, the material exhibits different surface tension value. The surface tension value can be calculated according to the Butler's Model [19-20]. For ternary alloy SAC 405, SAC 305 and SAC 105, the calculated surface tension was 546 mN/m^2, 544.9 mN/m^2 and 542.6 mN/m^2 respectively. It shows that the percentage addition of silver content in the SnCu alloy increases the surface tension of the molten solder alloy. The self-alignment force resulted from the surface tension of the solder alloy determine the self-alignment capability of chip component during reflow soldering. As indicated in Figures 5-6, the higher the silver content in the Sn-Ag-Cu alloy (up to 4 % Ag), the higher self-alignment capability of the chip component during reflow soldering. The surface tension data for SN100C was 542.45 mN/m^2. The value was approximately equivalent to SAC 105 solder. However, from the experiment, the self-alignment 0f SN100C solder yield better performance than SAC 105 solder and achieved almost equivalent performance as SAC 305 solder. The possible explanation for the behavior is that micro-alloy addition of Nickel in the SnCu alloy solder may improve the self-alignment of the solder.

Micro-alloy addition in the SnCu alloy improved fluidity of solder during reflow soldering process. The microstructural observations in the post-reflow show that increasing the nickel content reduces the volume fraction of primary Sn, thus causing a more-eutectic microstructure [21]. The molten fluid flows were able to flow easily before being stopped by solidification. Hence, the SN100C self-alignment during reflow soldering was better in comparison to SAC105 solder probably due to its superior molten metal fluidity characteristic.

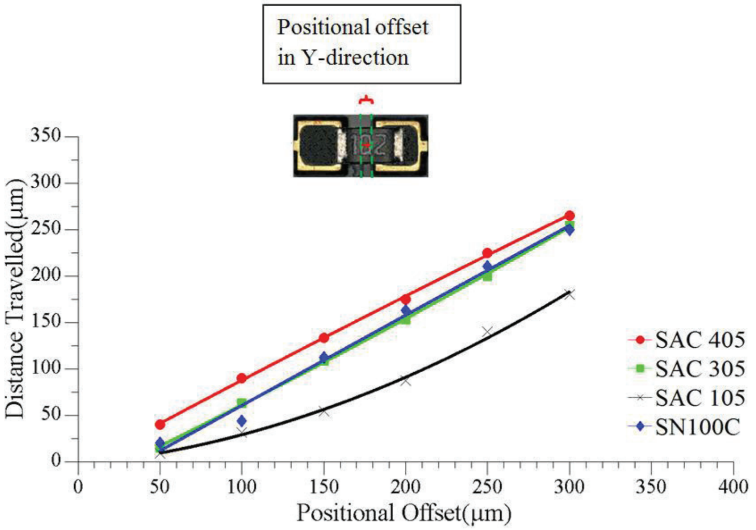

Figure 5: Y-Offset of resistor 0603 for solder SAC105, SAC305, SAC405 and SN100C

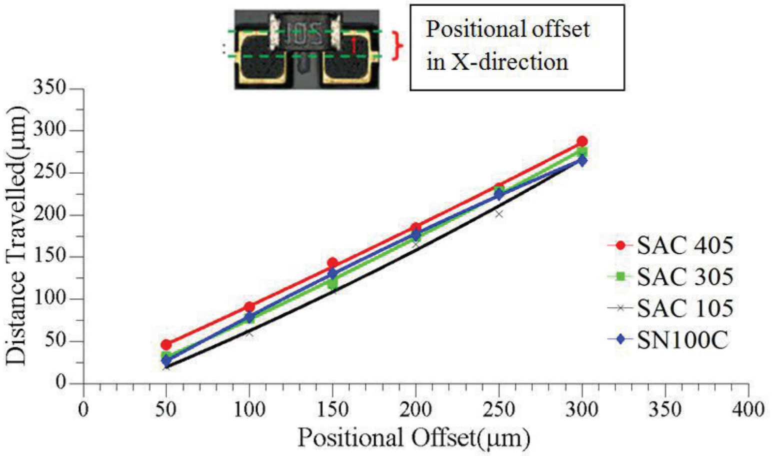

Figure 6: X-Offset of resistor 0603 for solder SAC105, SAC305, SAC405 and SN100C

4.0 CONCLUSION

In conclusion, the self-aligning ability of all chip components is better in the component width direction as to compare to its lengthwise axis direction for all the investigated lead-free solder. The Self-alignment capability performs at its best in high silver content solder; SAC405 solder followed by SAC305 and SAC105. It is in correlation with surface tension of the solder alloy of SAC type solder. However, the no silver content solder (SN100C), has self-alignment capabilities approximately similar to SAC305 solder due to micro addition of Nickel (0.05 %) in the solder alloy. A small addition of nickel into the SnCu solder alloy able to improve the fluidity of the alloy during self-alignment process.

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