Effect Of Temperature On Flexible Printed Circuit Board Layout During Reflow Soldering Process

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Abstract. High demands on flexibility, lighter weight, thinner size and low-cost electronic product had increased the application of Flexible Printed Circuit Board (FPCB) over Rigid Printed Circuit Board (RPCB). However, the thermal factor affects FPCB significantly during the reflow soldering process. The temperature of the reflow soldering process causes the FPCB to encounter significant deflection and thermal stress compared to the RPCB. Therefore, the present experiment investigates the effect of temperature on FPCB layout during the reflow soldering process. The deformation of RPCB and FPCB was measured using a KEYENCE LK-G152 laser sensor placed at the entrance and outlet of the reflow oven. Two temperature profiles were used as a variable for the experiment: soaking temperature profile and ramp temperature profile. The investigation shows that component placements pattern influences the deformation of FPCB. The FPCB component placements reduce the deformation due to low wetting angle and component weight. FPCB solder joint has a good wetting angle (<90°), indicating good solder paste deposited on the FPCB. However, several solder joints on FPCB are irregular in shape due to high deformation. Therefore, it is essential to study the effect of temperature on FPCB during the reflow soldering process for industries guideline for mass production of FPCB products.

INTRODUCTION

The Flexible Printed Circuit Board (FPCB) has unique capabilities, including reduced board thickness, added "twist" of flexibility, and the low-cost electronic product has encouraged people to research and development of FPCB to replace Rigid Printed Circuit Board (RPCB). FPCB has gained interest due to its mechanical flexibility that can bend to certain extend and light Weight because FPCB thickness is lower than RPCB [1][2]. FPCB has been used in several applications, such as mounted flow sensor on the FPCB for heat and flow detection and flexible wet sensor sheet to detect urination in the diaper. In addition, FPCB exhibits higher sensitivity compared to sensor fabricated on RPCB [3][4].

Lim et al. [1] had conducted several materials testing on FPCB. They perform a hot disk thermal analyser to find thermal conductivity and specific heat of FPCB. Hot Disk Thermal Analyser TPS 2500 was used using the Transient Plane Source technique (TPS) [5][1]. During the measurement, the TPS sensor was placed in between of FPCB layers. The density of FPCB was obtained using a weighing scale AUW220D with an accuracy of 0.1mg to measure the mass of FPCB. The FPCB mass obtained was divided by its own volume to obtain density. Young's Modulus and yield strength of FPCB were obtained by using INSTRON 3367 Universal Testing Machine. The result was obtained with a 95% confidence level [1]. Briggs et al. [6] studied two typical temperature profiles: ramp temperature profile and soaking temperature profile. Both temperature profile exhibit different behaviour on RPCB. However, both temperature profile must follow the melting temperature of solder paste. They find that soaking temperature profile cause higher deformation into RPCB due to thermal stress compared to ramp temperature profile [6].

Lau et al., [7] had optimised the reflow profiles to achieved high reliability of solder joints based on the heating factor by defect mechanism analysis. However, these methods involve many costly experiments. The study on solder paste behaviour during the reflow soldering process will help the manufacturing industry significantly. Many researchers had worked on thermal analysis of component assemblies during the reflow soldering process using numerical analysis and computer simulation. Moreover, Lau et al. [7] studied the thermal behaviour of a solder deposition pad on top of a multi-layer printed circuit board (PCB). The solder deposition pad was modelled using a multi-mode heat transfer numerical formulation and solved using a Finite Different Method (FDM). Khader et al. [8] studied the amount of solder paste during the stencil printing process. It is imperative to control the amount of solder paste, and the solder paste must ideally deposit to the targeted location to prevent the solder joint failures. Short and excessive deposition lead to various printing defects such as shifting, slumping, bridges and incompleteness. Solder paste failures also affected by squeegee speed and pressure, solder paste composition and stencil design [8]. Defects also cause due to thermal stress on solder paste. Thermal stress developed due to abrupt temperature change [9] For a typical reflow oven temperature profile, the temperature change is drastic from room temperature up to 250℃ and cooling process right after solder paste melting phase.

METHODOLOGY

Material preparation

For this experiment, single side FPCB consists of single copper, and single polyimide layers in total and its overall thickness is 0.053mm (Figure 1(a). The density of FPCB was obtained by using Shimadzu Weighing Scale AUW220D with an accuracy of 0.1mg. The mass of FPCB is measured and divided by its own volume. Tensile test was conducted by using INSTRON 3367 Universal Testing Machine(Figure 1(b) to obtain Young's Modulus and yield strength. The FPCB was tested at speed 0.25 mm/min based on ISO 527-3. Three samples had been tested with three samples were cut from FPCB

(a) (b)

FIGURE 1. (a) FPCB sample for testing and (b) INSTRON 3367 Universal Testing

Specific heat capacity was obtained by using Differential Scanning Calorimeter (DSC). First, FPCB, RPCB and solder paste were prepared about 5-10mg by using Shimadzu analytical balance AUW220D with an accuracy of 0.1mg. Then, the samples were placed into an aluminium Tzero pan. The heating rate for the test is 20℃/min, and the samples were heated from 30℃ to 300℃. The DSC experiment was conducted using argon with a mass flow rate setting of 50mL/min.

An empty aluminium Tzero pan was run and set as a baseline to determine the specific heat capacity. Next, the sapphire crimp pan was conducted as standard. Finally, the sample between 5-10mg was placed into the aluminium Tzero pan. The heat flow temperature curve of baseline, sapphire, and sample is used to calculate specific heat capacity at the desired temperature. The specific heat capacity (C_p) of the samples were calculated by using the following equation [10]:

$$C_p = \frac{60.D_s}{H_r.W_s}.E$$

Where:

C_p = Specific heat capacity

D_s = Heat flow different

H_r = Heating rate

W_s = weight of the sample

E = Ratio of the heat capacity of standard sapphire and measured heat capacity

Deformation Measurement of RPCB and FPCB Experimental Setup

This experiment used a KEYENCE LK-G152 laser sensor and was connected to the controller with 1μm accuracy with a read range of 11-18cm. It was installed at the inlet and outlet of the reflow oven to measure the deformation before and after the reflow soldering process due to the warpage phenomenon. The sensor is fixed by a magnetic stand and was placed on the non-vibrating part to reduce measurement error.

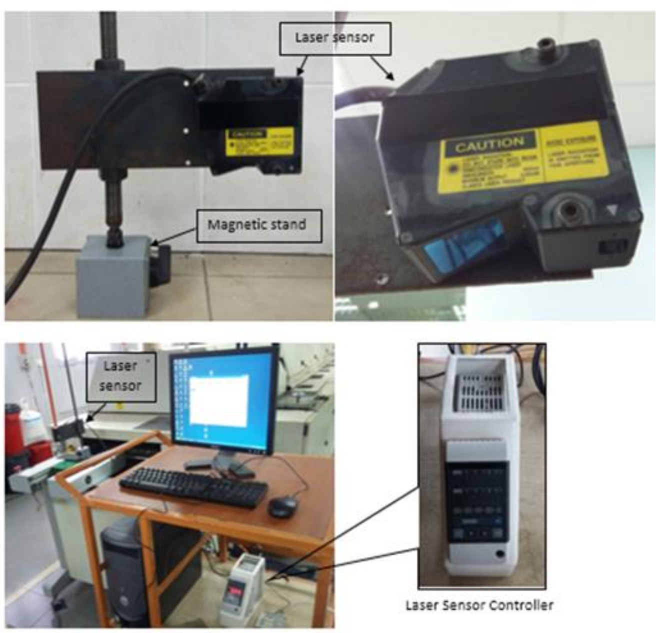


FIGURE 2. KEYENCE LK-G152 laser sensor connected with controller at the reflow oven outlet

Temperature profile and other setting were set at the computer connected with the BTU Paragon 150 Convection (Figure 3) Reflow Oven. For the experiment, two types of temperature profiles are used to compare for better control of RPCB and FPCB deformation during the reflow soldering process. Figure 4 shows the temperature profile over time for the reflow soldering process. The conveyor speed was set as 30 inches/min. After that, the test vehicle was placed on the reflow oven entrance conveyor to start the experiment. The laser sensor will measure the deformation of RPCB and FPCB at the outlet, and the quality of solder joints were inspected and recorded.

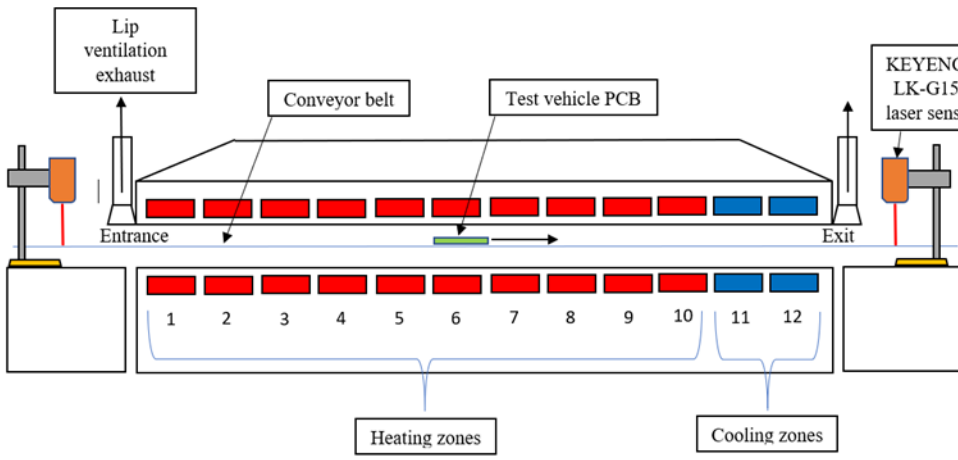


FIGURE 3. Schematic diagram of BTU Paragon 150 Convection Reflow Oven and KEYENCE LK-G152 laser sensor setup

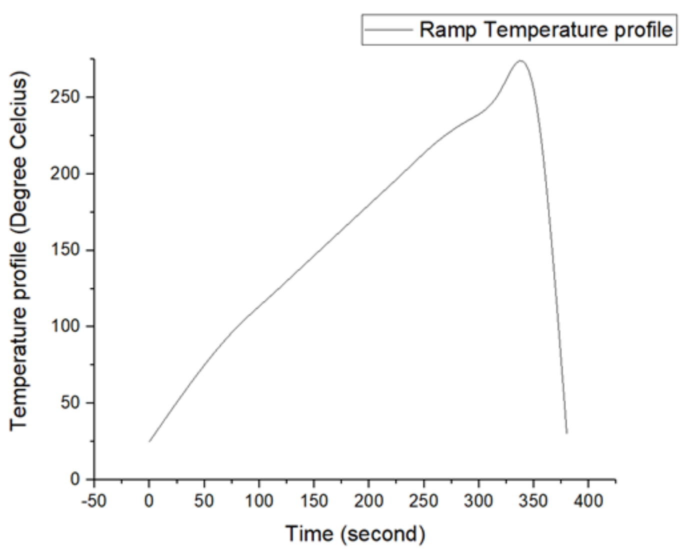


FIGURE 4. Graph of ramp temperature profile over time

EXPERIMENTAL SETUP

Component Layout Setup for Component Placement on FPCB and RPCB

The components were placed on RPCB and FPCB with a specific pattern to study the contribution of components placements on FPCB and RPCB deformation. There is three design of component placements which is Layout 1, Layout 2 and Layout 3 as shown in Figure 5. Each Layout had a different component placements configuration. The ramp temperature profile is used for this experiment because the ramp temperature profile gives minimum deformation on FPCB. FPCB result for Layout 1 is compared with RPCB. Solder paste $Sn_{3.0}Ag_{0.5}Cu$ or SAC 305 was used in this experiment, and capacitor used to represent surface mount devices (SMDs). SAC 305 is selected compared to SAC 105 and SAC 405 because it is widely used for electronic packaging components. The solder printing process was performed manually by aligned stencil on the RPCB and FPCB test vehicle. When the stencil was properly aligned, the solder paste was fill by using squeeze at an angle of 60°. After solder printing, the diodes were placed on the RPCB and FPCB test vehicle by using forceps onto the solder paste properly.

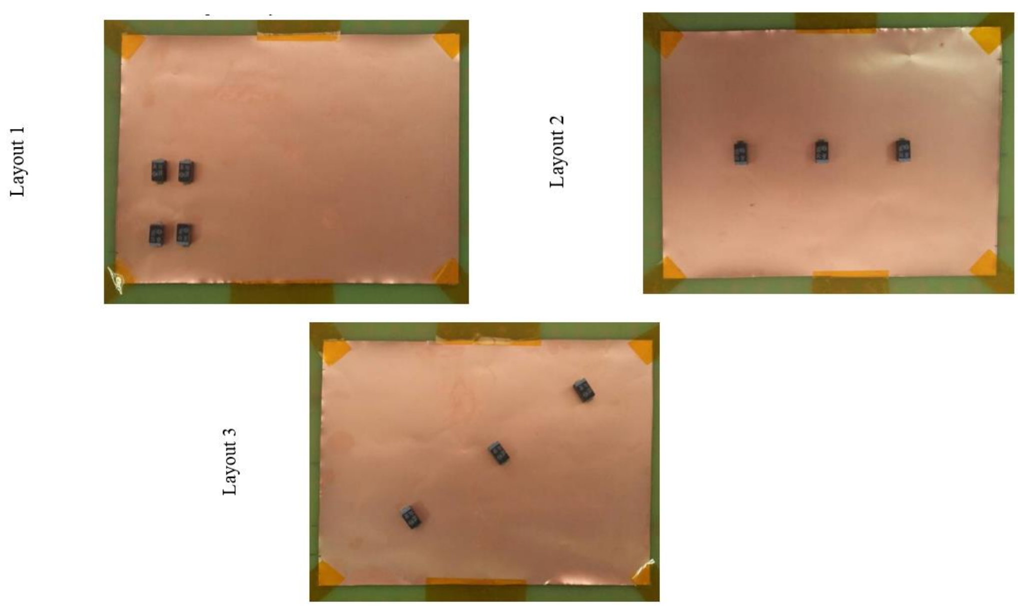


FIGURE 5. Component layout for RPCB.

Solder Joint Inspection

The solder joints of RPCB and FPCB were inspected using an Olympus microscope and captured by a Video Flex Ken-A-Vision camera which is connected to the computer, as shown in Figure 6. The solder joints were analysed to consider whether the solder joint is considered good or defect based on the visual characteristic of the solder joint with the component.

FIGURE 6. Olympus microscope equipment used to analyse solder joint

RESULTS

Effect of RPCB layout on deformation

The deformation of FPCB and RPCB without component attachment was conducted to study how the material properties and composition of FPCB and RPCB affected to the temperature profile of the reflow oven. Figure 7shows five points (point A, B, C, D and E) used to compare the initial displacement and final displacement of FPCB and RPCB when undergoing the reflow soldering process.

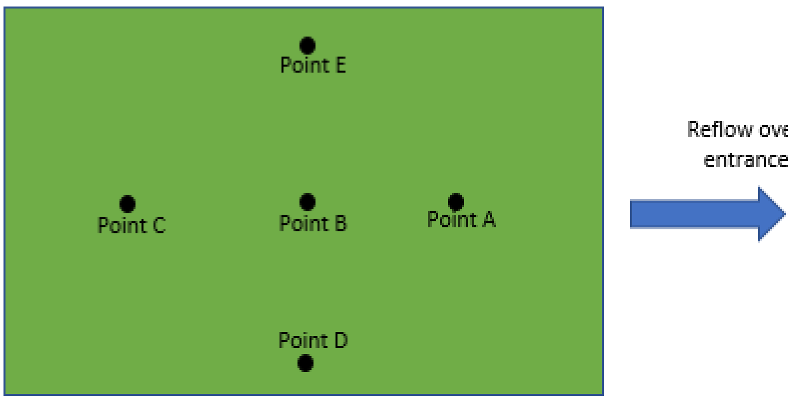


FIGURE 7. Schematic diagram of 5 points on FPCB and RPCB test vehicle

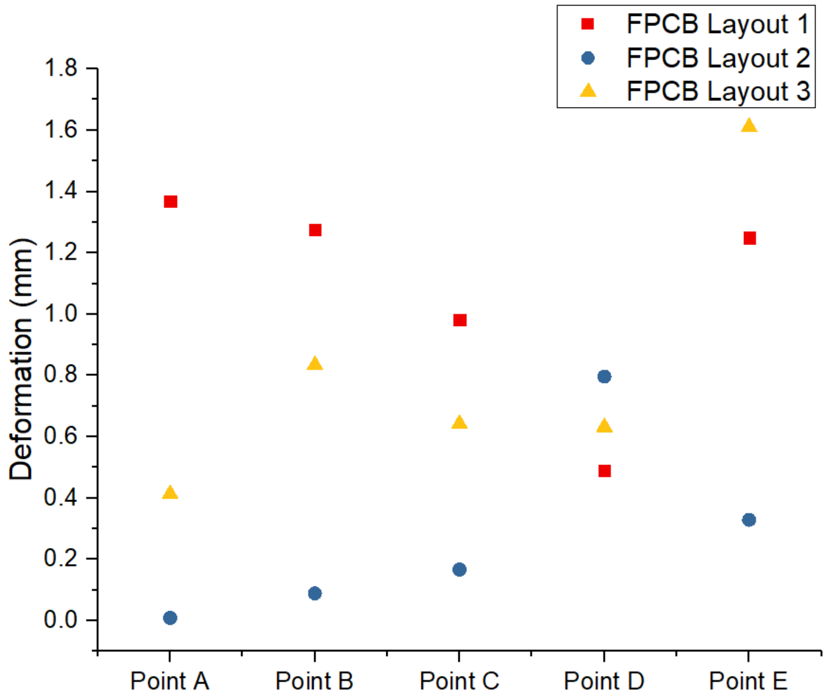


FIGURE 8. Graph of deformation of FPCB at different component Layout

Figure 8 shows the deformation pattern of FPCB at different layouts. Layout 1 demonstrated that the highest deformation for point A, B and C, followed by Layout 3 and Layout 2. Layout 2 had the lowest deformation because the component is placed around points A, B, and C. However, point Layout 2 got the highest deformation on Point E since no component placement around. Layout 1 had the highest deformation at point A, B and C because the components were arranged at the corner of the test vehicle, which is near point D. Hence, Point D had the lowest deformation for Layout 1 due to the high-density component placement. Layout 3 component placement where place diagonally throughout the test vehicle and produce unsteady deformation.

Effect of Component Placement of FPCB Deformation

Figure 9 shows the deformation pattern of FPCB at different layouts. The deformation of FPCB is reduced on the components placement pattern. Thermal expansion of the copper layer causes the FPCB to increase in length and make the FPCB deform upward. The component placement applies to weight, and the solder joint strengthens the bonding between the FPCB surface and solder joint cause it to minimise the deformation. The region with a component had high deformation compared to the area with component placement around.

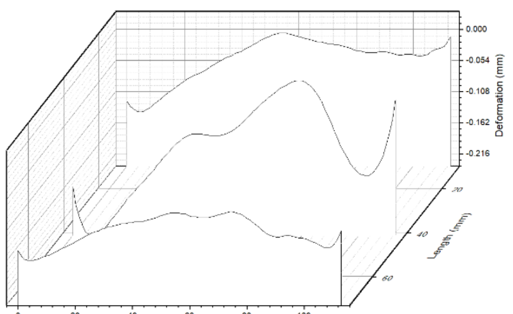
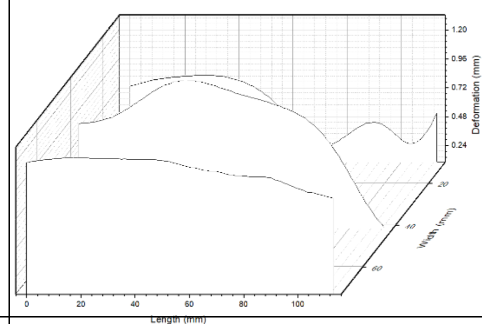
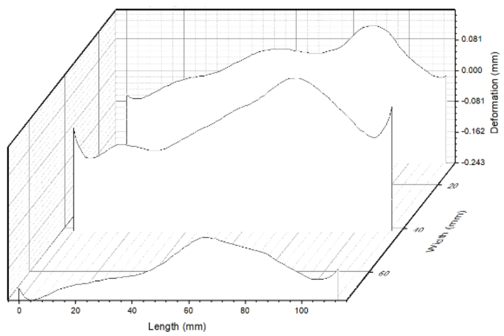
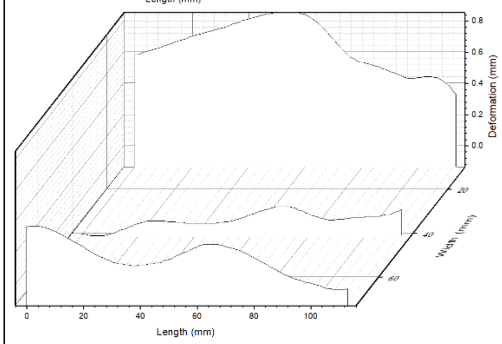
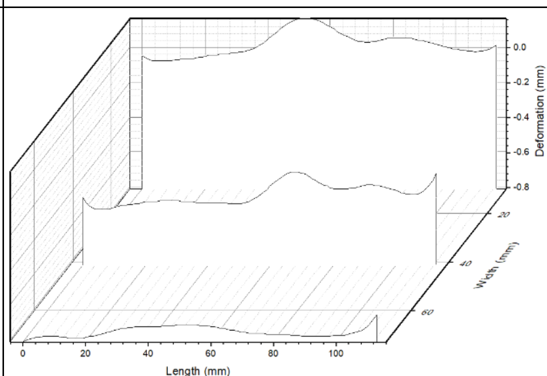
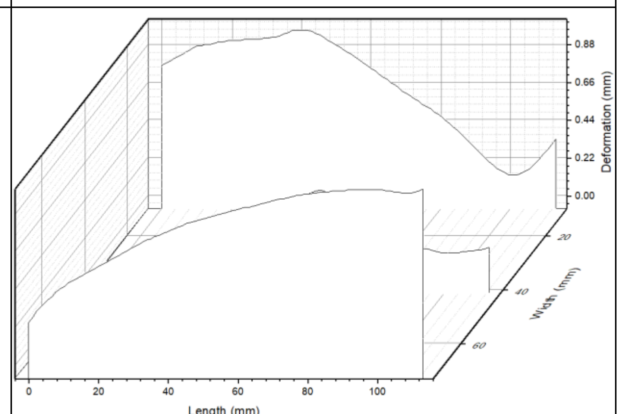
Data measured by KEYENCE LK-G152 laser sensor at different layouts		
	Initial	Final
Layout 1		
Layout 2		
Layout 3		

FIGURE 9. Deformation of FPCB at different component layout measured by KEYENCE LK-G152 laser sensor.

CONCLUSION

The experiment was conducted to study the effect of temperature profile on different FPCB layout. The result shows that the arrangement of FPCB influences the deformation of FPCB compared to the deformation of FPCB without component. A good wetting angle can reduce the deformation of FPCB because it strengthens the bond between the solder joint and the FPCB surface. The weight of the component causes downward vertical force on FPCB and reduce the deformation. Layout 1 has the highest deformation, follow by Layout 3 and Layout 2. The deformation of FPCB reduces at the region with component around.

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