Temperature Distribution Analysis during Solidification Process in Reflow Machine for Printed Circuit Board

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Abstract

In the semiconductor industry, Printed Circuit Board (PCB) is soldered by using an SMT Reflow Machine. It has several phases and within each phase, a temperature profile is fixed so that the solder paste could melt and cooled efficiently. However, uneven temperature distribution still poses a big challenge on reflow soldering of surface mount components. In this study, a non-conventional reflow oven is built to duplicate the reflow process and to improve the soldering quality of a PCB. The reflow oven prototype developed in this project has been tested and is able to be used to complete a soldering process but with a longer period of time. A comparison has been made which shows that both profiles obtained from conventional and industrial reflow oven have a similar trend. A simulation of the reflow soldering has also been done on selected IC component to study the temperature distribution on the component especially on the IC pins. It shows that heat transferred in both directions which are to the IC packages and circuit board. In the simulation results indicates that the process has an unequal distribution of thermal energy. Time study will be done to investigate the solidification process as obtained in experimental study.

Keywords: Parabolic dish, Stirling engine, solar energy, pyranometer, solar radiation

1.0 Introduction

Reflow soldering is a method of temporarily attaching one or hundreds of microscopic electrical components to their contact pads using a solder paste (a sticky mixture of powdered solder and flux), followed by controlled heating of the entire assembly. In a molten state, the solder paste reflows, forming permanent solder joints. A reflow machine, an infrared lamp, or (unconventionally) soldering individual joints with a desoldering hot air pencil can all be used to heat the assembly. In SMT reflow machine, there are several phases that the PCB should go through for a complete solidification. These phases are; Preheat, Thermal soak, Reflow and Cooling processes. Convection heating is chosen over infrared radiation technology in the reflow process of surface mount technology (SMT) [1]. Because convection heating can offer a more consistent temperature over a printed circuit board (PCB). However, uneven temperature distribution remains a serious problem during this process [2-5]. It is noticed that the peak temperature of each component on the boards are different. It is as if that the heat distribution in the reflow machine is not the same throughout the whole particular board. The solder paste does not melt simultaneously, and insufficient/excessive heating might occur. Insufficient heating reduces the cleaning effect of the flux, resulting in a lumpy or rough surface finish on non-reflowed or partially reflowed solder joints [6].

Excessive heating can cause flux activation and solder paste drying before the solder junction is formed. In practice, poor soldering can result in solder joint faults (such as skewing, bridging, voiding, and insufficient wetting), as well as electronic component failure and reliability difficulties. In this study, the work focused on developing and fabricating a nonconventional reflow oven to investigate the temperature distribution and time taken. This is important as temperature distribution may cause problems such as imperfect solidification in reflow machines. An analysis on IC model has been performed to visualize the solidification process using simulation based on previous studies [7-10].

2.0 Methodology

The research methodology involves three systematic procedures to fulfil the study's objectives and goals. Begin with experimental setup, then simulation parameters and undertaken simulation for material properties and thermal load.

2.1 Experimental setup

A standard oven has been used as unconventional reflow oven (Figure 1). Experiment has been conducted where data acquisition such as temperature sensor, timer, data logger and magnifier have been used throughout the study. The duration of each testing includes the process of soldering until the intended outcome is accomplished, which is to obtain a melting time that is uniform for the solder paste. For precise component attachment, controlling the reflow temperature curve is crucial. Component specifications will also affect the temperature curve used for this stage. The oven temperature has been set to 260°C according to solder paste's reflow specification. A quality inspection has been done by using magnifier to check the IC join between IC pins and circuit boards.

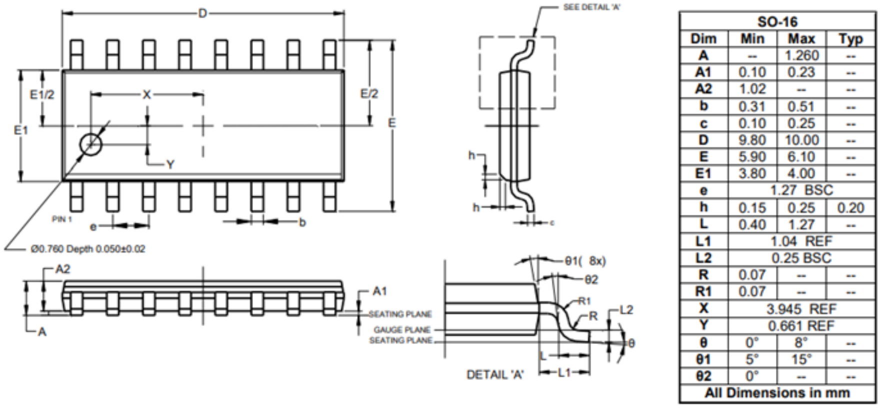
Figure 1: Unconventional reflow oven

2.2 Simulation Parameters

Another method used in this study is by using a computational analysis where simulation is carried out to visualize the solidification process. The details specification of selected IC component-S016 is given in Table 1 and Figure 2. The heat distribution during reflow was simulated using Solid Works. PCB, solder paste, SO16 pin, and SO16 body comprise the model. The pieces' dimensions are:

Table 1: Dimension of PCB and solder paste

NO	PARTS	DIMENSION (mm)
1	PCB	12x7.5x1.57
2	Solder paste	0.4x0.5x0.5



SO-16			
Dim	Min	Max	Typ
A	--	1.260	--
A1	0.10	0.23	--
A2	1.02	--	--
b	0.31	0.51	--
c	0.10	0.25	--
D	9.80	10.00	--
E	5.90	6.10	--
E1	3.80	4.00	--
e	1.27 BSC		
h	0.15	0.25	0.20
L	0.40	1.27	--
L1	1.04 REF		
L2	0.25 BSC		
R	0.07	--	--
R1	0.07	--	--
X	3.945 REF		
Y	0.661 REF		
θ	0°	8°	--
θ1	5°	15°	--
θ2	0°	--	--
All Dimensions in mm			

Figure 2: Dimension for SO16

2.3 Material Properties and Thermal Loads in Simulation

Each model component has its own material attributes. The SO16 pin, solder paste, and body were stainless steel, the paste was pure lead, and the body was silicon. The Solidwork library had all material information except FR-4, the PCB material. PCBs use most industrial FR-4. FR-4 was manually input as a custom material during manufacture. This study was simulated by raising the solder pad temperature to its maximum and measuring the heat distribution. The solder paste's body was heated to 307.9W to imitate its heat source. The SO16 pin, PCB, and solder paste have 250W and 100W thermal convection, respectively.

3.0 Result and Discussion

The experiment using nonconventional oven is able to get the temperature profiles similar to the industrial reflow machines. However, due to some restrictions, the process usually took longer than usual. This might be due to the manual temperature setting that slows ramp up. Theoretically, reflow soldering took 1.5 minutes based on standard reflow machines. As for simulation, Time-transient analysis is used to simulates model heating. This offers 800 seconds of 10-second temperature distribution monitoring.

3.1 Experimental result

Figure 3 shows the reflow profile from temperature distribution collected during experiment using nonconventional oven. Temperature and time data were collected after a number of experiments were done. Every 10 seconds, the temperature of the solder paste is measured. The maximum temperature achieved at 268.5°C and started to cool and solidify. Figure 4, 5 and 6 proof that the temperature profile obtained in Figure 3 has shown similarities with the results produced from commercial reflow oven. In industrial reflow machine, the distribution of the reflow temperature and the speed of the conveyor can be the main cause of the defects which also involved solder paste viscosity. In Figure 4 and 5, the results can be considered failed due to the soaking time is too long. It is based on the solder paste specification as the recommended time is between 20 – 60 second. The good result has been proofed in Figure 6 as the soaking time is 47.71 sec.

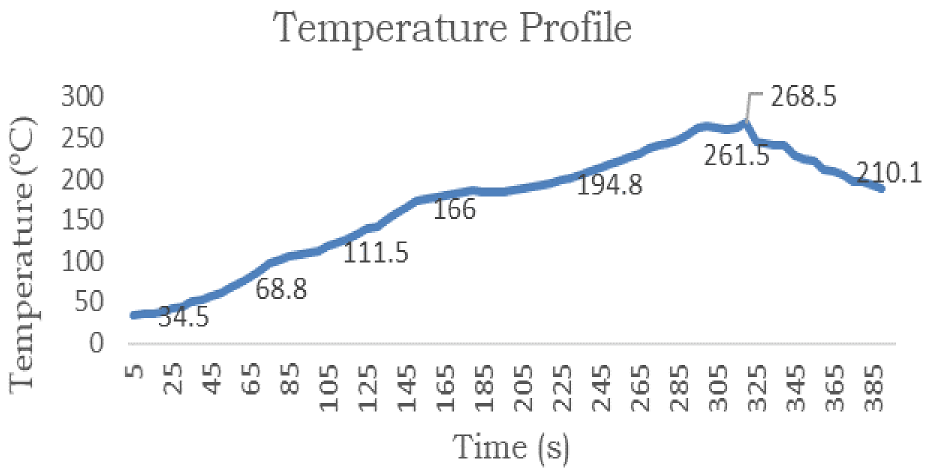


Figure 3: Temperature profile from experiment

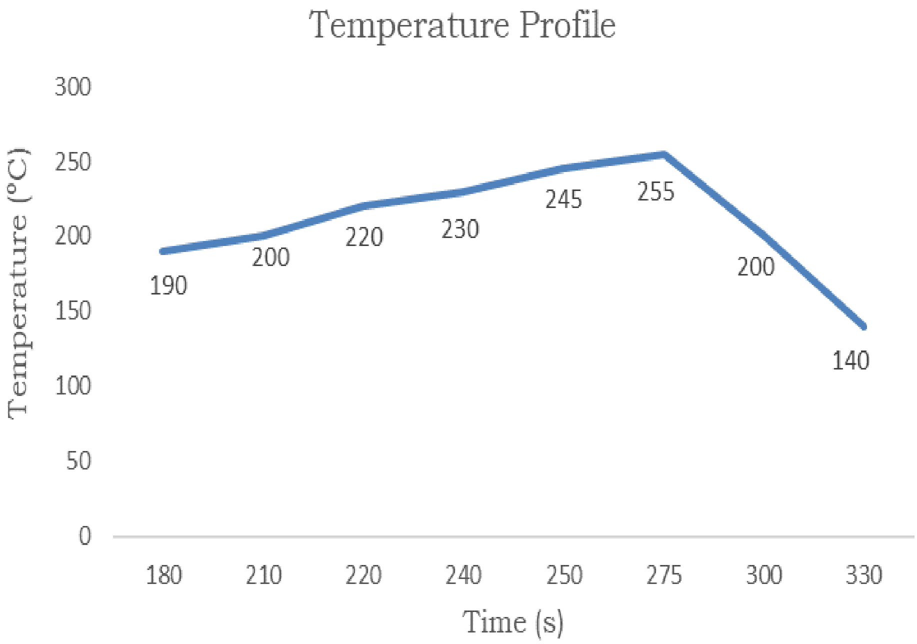


Figure 4: Temperature profile from reflow oven with low peak temperature and too long soaking time

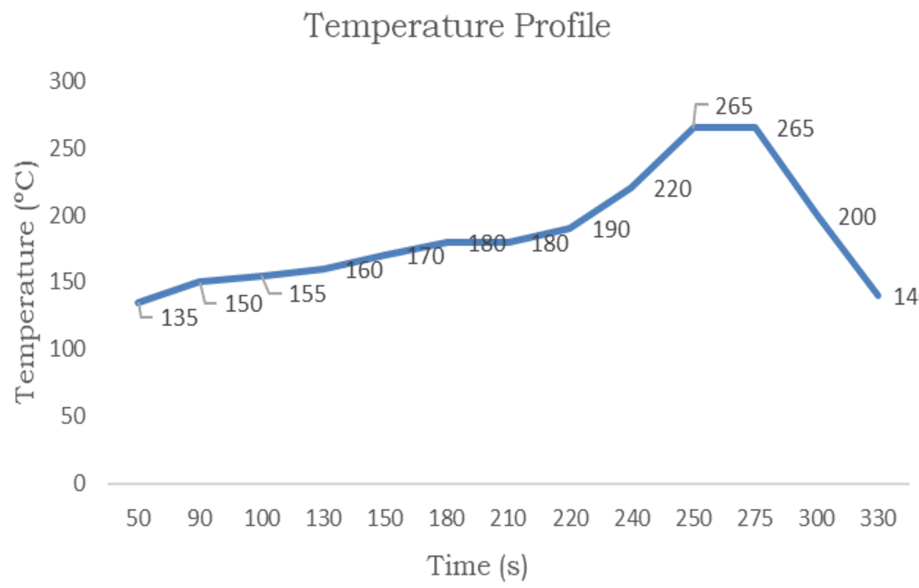


Figure 5: Temperature profile from reflow oven with high peak temperature and too long soaking time

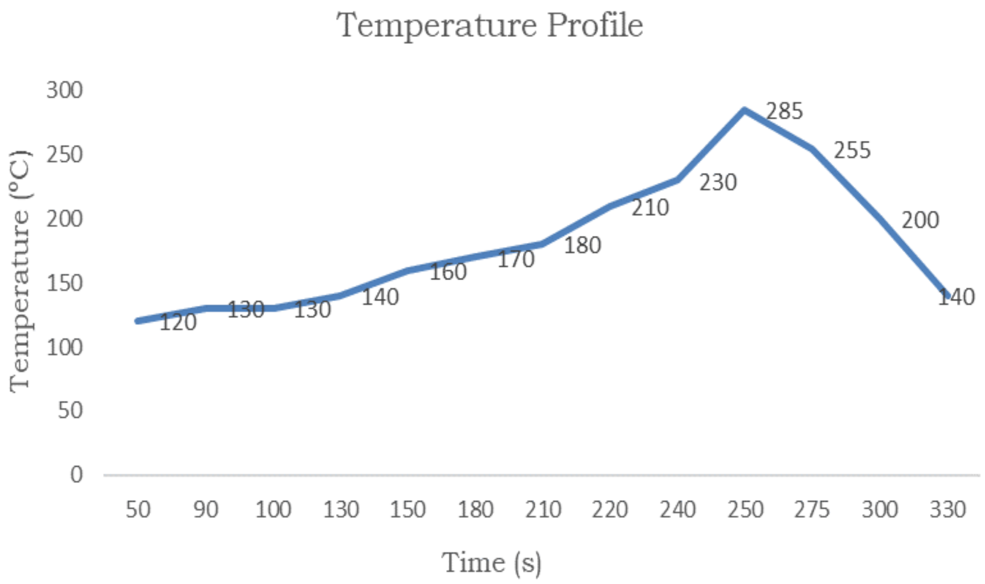


Figure 6: Temperature profile from reflow oven with high peak temperature and good soaking time

3.2 Simulation result

The results of the simulation in Figure 7 show that the process has an unequal distribution of thermal energy, which can be seen to be a problem. After being heated, the component will reach its maximum temperature at the solder that is located in the middle of the printed circuit board (PCB), while the temperature of the solder paste that is located at the end of the PCB will be lower. At the center of the solder paste, the highest value of 1.007e4 c is placed, while at the center of the printed circuit board (PCB), the minimum value of -9.589e1 c is placed.

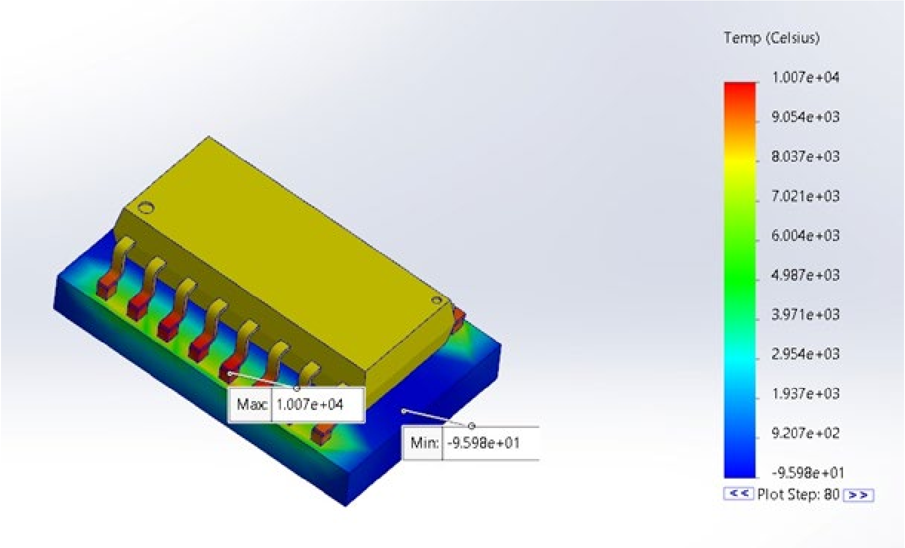


Figure 7: Temperature distribution plot

4.0 Conclusion

In overall, it was found that the non-conventional oven designed can mimic the reflow soldering method utilized in industrial reflow ovens and the data obtained can be used for reflow process optimization. The part has been soldered to the soldering board well. The data from the experiment was used to make a graph that showed the relationship between temperature and time. This graph was then compared to the data from the industry where similarities can be observed especially on the standard profiles. Based on the simulation results, it is clear that the reflow soldering does not heat the PCB evenly, which caused a bigger problem after production. Reflow soldering's uneven thermal distribution, too long soaking time and incorrect conveyer speed causes excessive and insufficient solder heating, where reworks and bad solder may result.

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Author Contributions

I.I Ismail: Original idea of study and conceptualization, Methodology, writing original draft preparation; **A.K. Ismail:** Data curation, Software, Validation, Supervision; **S.S. Riduan** and **K.A. Shamsuddin:** Software, Validation, Touch-up writing, reviewing and editing.

Conflicts of Interest

The manuscript has not been published elsewhere and is Not under consideration by other journals. All authors have approved the review, agree with its submission, and declare no conflict of interest in the manuscript.

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