Research on the Influence of Device Thermal Equivalent Model on the Temperature Field of Infrared Hot Air Reflow Soldering

Yutian Yin$^{1, \ast}$, Chenyang Ji$^b$, Yubing Gong$^{c\ast}$

$^1$School of Mechanical & Electrical Engineering, Guilin University of electronic technology, Guilin, Guangxi, 541004, China
$^2$The 34th Research Institute of China Electronics Technology Group Corporation
$^a$yytstudent@163.com, $^b$JiChenyang1166@163.com, $^c$gybcome@guet.edu.cn

Abstract. Infrared hot air reflow soldering is an important process in SMT assembly process. The temperature field of infrared hot air reflow soldering of PCBA will directly affect the reliability of solder joints. The different simplified equivalent models have a certain influence on the temperature field of infrared hot air reflow soldering PCBA, which is mainly reflected in accuracy and efficiency. This paper studies the influence of three different thermal models on the temperature field of reflow soldering PCBA, and selects four groups of points in the same position of the three models, and comprehensively compares their temperatures. The results show that the maximum temperature deviation of the three models is as high as 7℃ in the soldering zone and 4℃ in the cooling zone, and the temperature difference is small. It can be concluded that the complex solder ball model can be used for high precision applications, and the simplified single-layer solder model and the thermal equivalent model can be used for low precision applications. These conclusions provide some references for the modeling of infrared hot air reflow soldering.

1. Introduction

In today's society, surface mount technology (SMT) has developed rapidly and is widely used in the electronics manufacturing industry, and has a gradual development trend towards lightness and density [1]. Infrared hot air reflow soldering has a pivotal position among them. Among them, components, circuit boards and solder joints are closely related to the quality and life of electronic products. Therefore, quickly adjusting the temperature field of the reflow soldering process has become the top priority of engineering research. However, in actual production, the reflow soldering process has a far greater impact on soldering defects than printing, patching, solder paste materials, components, etc., and the setting of reflow soldering parameters directly determines the reflow soldering accuracy [2]. Therefore, when inspecting the quality of the finished product, if there is a problem, it will be necessary to adjust and reset the soldering process parameters. This will cost a lot of manpower and material resources, which will greatly increase the manufacturing cost. Therefore, the simulation study of the reflow soldering process is the practical significance.

This paper uses Ansys workbench to simulate the infrared hot air reflow soldering temperature field and model the PCB board. The models include the traditional solder ball model, the simplified one-layer solder model and the further simplified device thermal equivalent model. And build related temperature models in the form of parameters, and set different and representative special points on the PCB board. Under the four temperature zones of preheating, heat preservation, reflow, and cooling, compare the
effects of the three simplified models on the PCBA temperature field. According to the results, whether the simplified equivalent model can be instead of traditional models is discussed, it is used to reduce the calculation scale and save production costs.

2. Finite element simulation of temperature field of infrared hot air reflow soldering BGA

2.1 Boundary conditions of temperature field
In the process of reflow soldering heating of PCBA simulated in this design, heat is mainly transferred to PCB through convection, and also contains a small part of heat radiation and heat conduction. In the process of reflow soldering, reflow furnace heat transfer between PCBA and mainly through the convection heat transfer of the gas and thermal radiation of reheating furnace chamber for PCBS [3], but the heat convection and thermal radiation calculation has the very big difference, in order to be more conducive to calculate, in this study, the radiation heat transfer into convective heat transfer is calculated.

2.2 Finite element model
In this paper, a practical PCBA was modeled and simulated. Because the composite structure of the actual PCB component was relatively complex, and there were many internal electrical layers, and the thermal properties of the material were anisotropic, the geometric model composed of simple components was established by ANSYS Space Claim for the early modeling and simulation of the temperature field. PCBA and components are simplified as cuboids, without considering the actual circuit board wiring, the printed circuit is simplified as two layers of copper foil with a specified thickness, and the anisotropic material is simplified as isotropic material properties; some material parameters of brazing pad and FR4 substrate are listed in Table 1 and 2, and the remaining material parameters are shown in literature [4]. The external size of PCB is 160mm×100mm×1.63mm, as shown in Figure 1. PCB substrate FR-4, copper clad foil; PCB substrate size is 160mm×100mm×1.47mm, copper foil size is 160mm×100mm×0.08mm; the solder ball model contains 285,308 nodes and 113,401 cells; the single-layer solder finite element model contains 206,136 nodes and 83,475 elements. The thermal equivalent finite element model consists of 205,418 nodes and 83,174 elements, as shown in Fig. 2(a), 2(b) and 2(c).

Table 1 Thermal conductivity and specific heat capacity of Cu pads

| T (°C) | 20 | 80 | 120 | 160 | 200 | 225 | 240 |
|--------|----|----|-----|-----|-----|-----|-----|
| cp (J·kg⁻¹·°C⁻¹) | 356.8 | 375.5 | 388.0 | 400.4 | 412.8 | 420.6 | 425.3 |
| K (W·m⁻¹·°C⁻¹) | 521.5 | 532.0 | 539.0 | 546.0 | 553.3 | 557.7 | 560.0 |

Table 2 The specific heat (cp) of FR-4 substrate at different temperatures

| T (°C) | 20 | 80 | 120 | 160 | 200 | 225 | 240 |
|--------|----|----|-----|-----|-----|-----|-----|
| cp (J·kg⁻¹·°C⁻¹) | 1100 | 1400 | 1500 | 1550 | 1600 | 1610 | 1640 |

Figure 1 PCBA physical and two-dimensional structure diagram
2.3 Setting of loading conditions

In this paper, infrared hot air reflow soldering furnace is selected and 12 temperature zones are set. The temperature setting of furnace area is shown in Table 3 below. The speed of the conveyor belt was set as 13.33cm/s, and the thermal load (convective heat transfer coefficient H, hot air temperature T) varied with time was loaded on the PCBA finite element model using APDL language, so as to realize the thermal load of temperature field in 12 temperature zones.

| Furnace area | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 |
|--------------|---|---|---|---|---|---|---|---|---|----|----|----|
| T (℃)        | 125 | 150 | 160 | 170 | 175 | 175 | 200 | 240 | 227 | 180 | 150 | 140 |
| Features     | Preheat | Keep warm | Reflow area | Cool down |

2.4 Simulation results and post-processing

The temperature field distribution diagram of PCBA is obtained through simulation, as shown in Figures 3, 4 and 5.

When the PCBA component is reflow soldering simulation to 242s, the solder paste temperature curve is shown in Figure 6, 7 and 8.

3. The effect of device thermal equivalent model on the temperature field of infrared hot air reflow soldering PCBA

3.1 Setting up research sites

In order to facilitate the analysis of the influence of different thermal models on the PCBA temperature field during reflow soldering, the above three models are imported into the simulation program, and then six sets of points are set on the same position of the three models for research. Take the center point of the BGA surface (research point 1), the center point of the bottom of the BGA (research point 2), the center point of the chip 2 surface (research point 3), the center point of the bottom of the chip 2 (research point 4), as shown in Figures 9, 10, 11, and 12.
3.2 Comparison of the influence of three models on the temperature field during infrared hot air reflow soldering

The highest values of the data are extracted from the four temperature zones, and the comparison results are shown in Tables 4 below.

| Table 4 Temperature extraction at each study site |
|-----------------------------------------------|
| Solder joint model | One-layer solder model | Thermal equivalent model | Solder joint model | One-layer solder model | Thermal equivalent model |
| Preheating zone | 133.25°C | 135.8°C | 135.93°C | 136.49°C | 137°C | 135.85°C |
| Insulation area | 168.51°C | 169.94°C | 170.61°C | 169.49°C | 169.94°C | 169.13°C |
| Reflow area | 220.06°C | 222.41°C | 222.87°C | 222.53°C | 223.08°C | 222.01°C |
| Cooling zone | 215.89°C | 216.89°C | 214.49°C | 219.8°C | 219.81°C | 219.5°C |
| Preheating zone | 129.94°C | 136.55°C | 132.97°C | 136.18°C | 136.61°C | 135.59°C |
| Insulation area | 166.41°C | 169.49°C | 167.37°C | 168.46°C | 168.78°C | 168.18°C |
| Reflow area | 216.83°C | 221.46°C | 220.52°C | 222.8°C | 223.24°C | 222.41°C |
According to the above data:
1. According to Figure 13 and Table 4, at the center point of the BGA surface, the temperature of the single-layer solder model was larger in the heating zone and cooling zone, with a difference of about 0°C ~3°C, based on the solder ball model results. The temperature of the thermal equivalent model is larger in the heating zone, with a difference of about 2°C ~3°C. The cooling zone is small, with a difference of about 2°C.
2. According to Figure 14 and Table 4, at the center of the bottom of the BGA, the temperature of the single-layer solder model and the solder ball model are both larger than that of the heating zone and cooling zone, with a difference of about 0°C ~1°C. The temperature of the thermal equivalent model and the solder ball model are smaller than that of the solder ball model, with a difference of about 0°C ~1°C.
3. As can be seen from Figure 15 and Table 4, at the center point of chip 2 surface, the temperature of single-layer solder model and solder ball model is larger than that of heating zone and cooling zone, with a difference of about 2°C ~7°C. The temperature of the thermal equivalent model is larger than that of the heating zone and the cooling zone, with a difference of about 0°C ~4°C.
4. According to Figure 16 and Table 4, at the bottom center point of chip 2, the temperature of the single-layer solder model and the solder ball model are both larger than that of the heating zone and cooling zone, with a difference of about 0°C ~1°C. The temperature of the thermal equivalent model is smaller than that of the heating zone and cooling zone, with a difference of about 0°C ~1°C.

The deviations of the single-layer solder model and thermal equivalent model from the solder ball model at each study site are shown in Tables 5.

Table 5 Comparison of temperature deviations between mono-layer solder model and thermal equivalent model for solder ball model

| Research point | Single layer solder model | Thermal equivalent model |
|----------------|---------------------------|--------------------------|
| Heating zone   | 0°C ~ +3°C                 | 0°C ~ +1°C               |
|                | 0°C ~ +1°C                 | 0°C ~ +1°C               |
|                | +1°C ~ +4°C                | 0°C ~ +1°C               |
|                | +2°C ~ +3°C                | 0°C ~ +1°C               |
|                | +7°C ~ -1°C                | 0°C ~ +1°C               |
| Cooling zone   | +1°C ~ -1°C                | +1°C ~ -1°C              |
|                | 0°C ~ +1°C                 | 0°C ~ +1°C               |
|                | +2°C ~ +3°C                | 0°C ~ +1°C               |
|                | +7°C ~ -1°C                | 0°C ~ +1°C               |
|                | +2°C ~ +3°C                | 0°C ~ +1°C               |

It can be seen that the three models have basically the same influence on the temperature field of PCBA infrared hot air reflow soldering.

4. Conclusion
With PCBA as the research object, this paper has carried out thermal analysis to the entire model, simulation with reflow soldering temperature field, analyzes the device thermal equivalent model of temperature field in the infrared hot air reflow soldering PCBA, and three kinds of simulation data analysis model of the infrared hot air reflow soldering PCBA difference are small, the influence of the temperature field under certain conditions can use thermal equivalent model to replace the traditional complex model for studying the effects on the temperature field. It can also be said that complex solder ball models can be used in high precision production, and simplified single-layer solder models and thermal equivalent models can be used in low precision production.

Acknowledgements
The authors gratefully acknowledge the financial support for this work from the National Defense Basic Scientific Research program of China (No.JSZL2018204B003), the National Natural Science Foundation of China (NSFC) (No. 51965012) and the key research and development plan of Guangxi Province of China (No. AB18126002).

References
[1] Pan Kaolin, Zhou Dejian . Study on Simulation of Reflow Soldering Process of SMT[J]. Electronics Process Technology,2000,21(5) :185-187. [In Chinese]
[2] Yubing Gong. Study on Optimization of Furnace Temperature Profile Under Reflow Soldering[J]. Hot Working Technology, 2013;45(15):187-190. [In Chinese]
[3] B. Illé, Measuring heat transfer coefficient in convection reflow ovens. Measurement 43(2010)1134-1141.
B. Illés, I. Bakó, Numerical study of the gas flow velocity space in convection reflow oven. International Journal of Heat and Mass Transfer 70 (2014) 185-191.

[4] Piotr B, Hakim N Alain R. Moving least squares response surface approximation: Formulation and metal forming applications [J]. Computers & Structures. 2006, 83 (17-18): 1411-1428.
Zhi Li Sun, Yu Guo, Er Shun Pan, Wei Song. Reflow Soldering Process Virtual Test Based on BPNN-GA and ANSYS. Applied Mechanics and Materials Vol.281(2013)pp417-421.