Research on Welding Temperature Based on Unsteady Thermal Convection

Wenbo Li[1], Yuxin Li[2], Qiaomu Wang[3]

[1]School of Physics, Zhengzhou University, Zhengzhou, Henan 450001

[2]School of Business, Central South University, Changsha, Hunan 410000

[3]School of Mechanical Engineering, Nanjing University of Science and Technology, Nanjing, Jiangsu 210094

Keywords: Energy conservation, second order differential, furnace temperature curve.

Abstract: How to make reflow soldering furnace each temperature zone to maintain the process required temperature is an important issue in the production of electronic products such as integrated circuit boards. For the portrayal of the temperature variation in the center of the soldering region. First, the heat exchange difference model is established considering Newton's law of cooling, thermal convection heat dissipation theorem and the law of conservation of energy. Secondly, the heat exchange model is discretized, while the second-order forward difference equation is obtained based on the fact that the board processing time lags. After that, according to the third category of heat exchange boundary conditions and the temperature set value of each temperature zone, determine the temperature-time boundary and constraints; finally, through the iterative algorithm based on $\Delta t = 0.5s$ to time layer by layer solution, to obtain the temperature variation in the time-space dimension and the corresponding furnace temperature curve is inscribed, the midpoint of small temperature zone 3, 6, 7 and the temperature of the center of the welding region at the end of the small temperature zone 8 are: $\mu_{3c} = 123.323°C, \mu_{6c} = 162.8125°C, \mu_{7c} = 170.2375°C, \quad \mu_{8e} = 207.2599°C$.

1. Introduction

In the production of electronic products such as integrated circuit boards, printed circuit boards with various electronic components are placed in a solder-back oven, where they are heated and processed in such a way that the electronic components are automatically soldered to the board [1]. During the production process, the temperature of each part of the reflow oven needs to be controlled and adjusted through experimental tests. It is especially important to keep the various parts of the reflow oven at the temperature required by the process for simulation in the test to ensure the quality of the product and reduce production costs [2]. Inside the reflow furnace is divided into 4 large temperature zones, which are preheating zone, constant temperature zone, reflow zone, and cooling zone. The set temperature of each zone can be adjusted within ±10°C. The adjustment range of the conveyor belt over the furnace speed is [65, 100] min. During the experiment, the temperature sensor starts to work when the temperature in the center of the soldering area reaches 30°C and the board enters the solderback furnace to start the timing [3].

Given the length of the front and rear areas of the furnace, the length of the small temperature zone, the gap between adjacent temperature zones and other parameter values, the production plant temperature of 75, the conveyor belt over the furnace speed of 78cm/min, the set value of the temperature of each temperature zone are 173°C, 198°C, 230°C and 257°C as well as in the furnace temperature curve to meet the requirements of the process boundary, the requirements of the mathematical model and specify the temperature of the center of the soldering area Variation and plot the corresponding furnace temperature curve, while calculating its specific temperature values at the midpoint of small temperature zones 3, 6, 7 and the end of the small temperature zone 8.

  DOI: 10.25236/iemb.2021.005

2. Newton's law of cooling

The law followed by an object whose temperature is higher than the surrounding environment when it transfers heat to the surrounding medium for gradual cooling. When there is a temperature difference between the surface of the object and its surroundings, the heat loss per unit time from the unit area is proportional to the temperature difference, and the proportionality coefficient is called the heat transfer coefficient. It is one of the basic laws of heat transfer and is used to calculate the amount of convective heat.

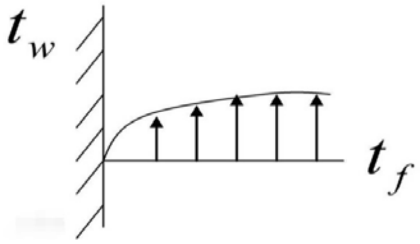

Figure 1. Object cooling process

3. Welding zone temperature model

3.1 Temperature variation model based on the internal parts of the reflow furnace

We model the temperature variation of each part of the reflow furnace (including each small temperature zone and its boundary as well as the gap between small temperature zones) by the thermal convection heat dissipation equation. First, based on the heat convection equation of thermal Ohm's law of heat conduction, Δx at any location inside the reflow furnace has the following equation:

$$W_i = h_i \times (x_{i2} - x_{i1}) \times \int_{x_{i1}}^{x_{i2}} \frac{|\mu_n - \mu_{n+1}|}{\Delta x} dx = h_i \times (x_{i2} - x_{i1}) \times \int_{x_{i1}}^{x_{i2}} \frac{\partial \mu}{\Delta x} \partial \mathrm{x}$$

Further reasoning yields Eq.

$$\frac{\partial W_i}{\partial x} = a \times \frac{\partial \mu}{\partial x}$$

Where a denotes the scale factor, which is the product of the convective heat transfer coefficient of the surface and the temperature difference in numerical terms.

3.2 Temperature-time variation model based on the center of the welding area

Firstly, Newton's law of cooling shows that when there is a temperature difference between the surface of an object and its surroundings, the heat dissipated per unit time from a unit area is proportional to the temperature difference, where the proportionality factor is called the surface convective heat transfer coefficient. Therefore, the heat dissipated by a hot convective gas per unit time can be expressed as the following equation:

$$Q_1 = h_i \Delta T$$

Based on the specific heat capacity formula, the heat absorbed by an object per unit time is given by the following equation.

$$Q_2 = cm\Delta T$$

At the same time, the center of the welding region is considered as a point of mass, and the idea of the micro-element is applied, which is considered to have an infinite convergence to a unit of mass. Based on the law of conservation of energy as well as taking into account the heating hysteresis problem, a finite second-order difference equation based on thermal convection conditions is established as follows.

$$\frac{\partial \mu}{\partial t} = -\frac{c_{i-1}}{c_i} \frac{\partial \mu}{\partial (t-1)} + \frac{2h_i}{c_i} \left[\mu_n - \mu(t-1) \right]$$

3.3 Consider the limits and boundary conditions of the temperature change model

(1) Determining the limiting conditions

Firstly, according to the requirements of each small temperature zone temperature setting values of 173°C (small temperature zone 1~5), 198°C (small temperature zone 6), 230°C (small temperature zone 7), 257°C (small temperature zone 8~9) has been the cooling zone (small temperature zone 10~11) temperature constant 25°C, the temperature setting limits of each small temperature to adjust. We note that the temperature sensor starts to work only when the temperature in the center of the welding area reaches 30°C. The constraints of the time-temperature variation model are:

$$\begin{cases} \mu_1=\mu_2=\mu_3=\mu_4=\mu_5=173 \\ \mu_6=198 \\ \mu_7=230 \\ \mu_8=\mu_9=257 \\ \mu(t)\geq 30 \end{cases}$$

(2) Determination of boundary conditions

For small temperature zone 1, consider the remaining small temperature zone n, whose left side is in contact with the gap between the small temperature zone, and thus its edge temperature may be influenced by the temperature of the adjacent small temperature zone, the left boundary edge condition of small temperature zone n is

$$\mu\left[(n-1)(d+S),t\right]=\mu(x),t\in\left[0,T\right]$$

For small temperature zone 10, because it is in the cooling zone with a constant temperature of 25°C, its temperature is the same as the constant cooling zone temperature, so the right boundary margin condition for small temperature zone 10 is

$$\mu[10d+9S,t]=25,t\in\left[0,T\right]$$

For small temperature zone 11, because its right side is in contact with the outside world, and thus its temperature is the same as the constant outside temperature, the right boundary side condition of small temperature zone 11 is

$$\mu(11d+10S,t)=25,t\in\left[0,T\right]$$

For the remaining small temperature zone n, its edge temperature may be influenced by the temperature of the adjacent small temperature zone because of the gap contact between its right side and the small temperature zone. Therefore, the right boundary edge condition of the small temperature zone n can be expressed as:

$$\mu\left[nd+(n-1)S,t\right]=\mu(x),t\in\left[0,T\right]$$

In summary, the model boundary conditions can be expressed as:

$$\begin{cases} \mu(0,t)=25 \\ \mu\left[(n-1)(d+S),t\right]=\mu(x) \\ \mu[(10d+9S),t]=25 \\ \mu[(11d+10S),t]=25 \\ \mu\left[nd+(n-1)S,t\right] \\ t\in[0,T] \end{cases}$$

The best-fit coefficients obtained by solving the attached data according to the above solution steps are shown in Table 1.

Table.1. Meaning and value of correlation coefficient

Symbols	k_1	k_2	k_3
Meaning	$1-\frac{h_i}{c_i}-\frac{c_{i-1}}{c_i}$	$\frac{c_{i-1}}{c_i}$	$-\frac{h_i}{c_i}$
Numerical value	0.0616	1.9591	-0.9595

Among them, $\mu(t)=(1-\frac{h_i}{c_i}-\frac{c_{i-1}}{c_i})\mu(t-1)+\frac{c_{i-1}}{c_i}\mu(t-2)-\frac{h_i}{c_i}\mu_n$.

At this point the non-stationary heat transfer model inscribed in the center of the welding region temperature and time graph plotted as shown in Fig. 2.

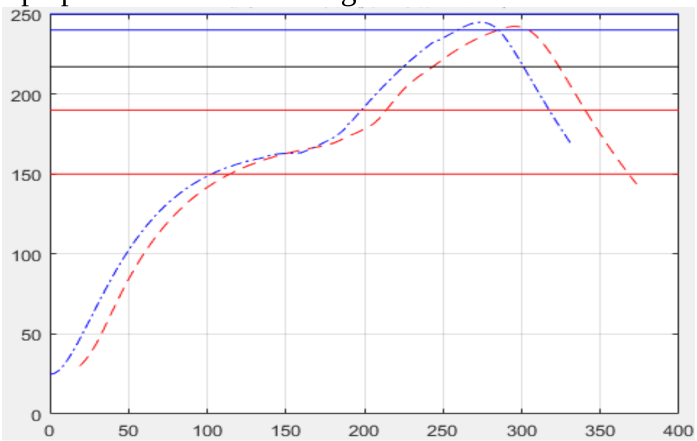

Figure 2. Furnace temperature profile under unsteady thermal convection model

According to the correlation coefficients obtained, a non-stationary heat transfer model is applied to portray the temperature-time distribution. The temperature variation in the center of the welded area is plotted and the corresponding derivative curve is shown below.

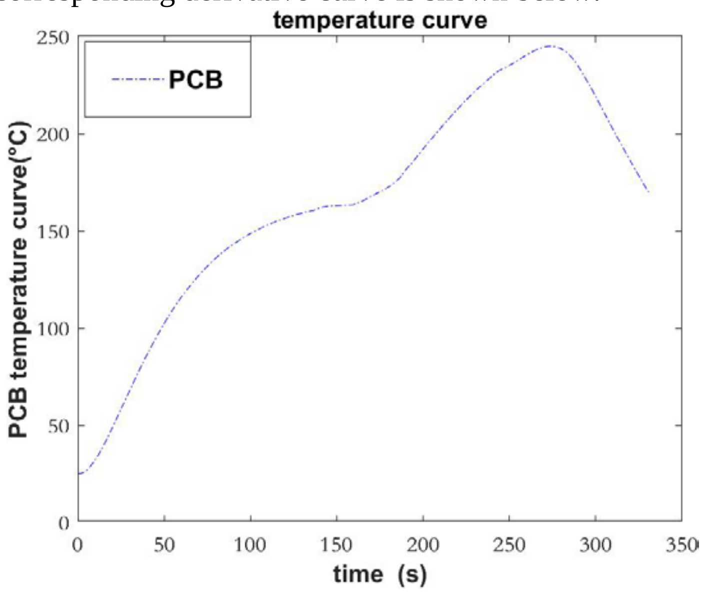

Figure 3. Graph of non-stationary thermal convection furnace temperature curve

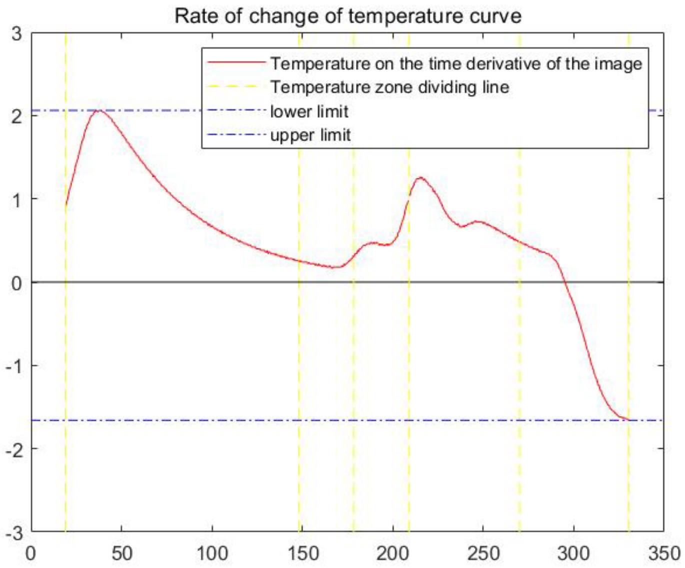

Figure 4. Temperature derivative curve with respect to time

We found that the temperature in the center of the welding zone is always lower than the temperature in the preheat zone, the constant temperature zone, and the reflow zone. Combined with the derivative curve of temperature with respect to time, it is easy to find that the temperature in the center of the weld zone has been showing an increasing trend during the process (except for the cooling zone), i.e., the gap between the small temperature zones does not have a significant impact on the furnace temperature. The center of the welding area in just entering the preheating zone, the temperature growth and growth rate trend shows an accelerating trend, which mainly depends on the surface convective heat transfer coefficient h, part of the temperature distribution data shown in Table 2.

Table.2. Selected temperature data of the center of the welding area

Time/s	Displacement/m	Temperature/ $°C$
66.5s	86.45cm ($\Delta d_{3c}^{+} = 0.2cm$)	$123.323°C$
148.5s	193.05cm ($\Delta d_{6c}^{+} = 0.3cm$)	$162.8125°C$
175.5s	228.15cm ($\Delta d_{7c}^{-} = 0.1cm$)	$170.2375°C$
214.5s	278.85cm ($\Delta d_{8e}^{-} = 0.15cm$)	$207.2599°C$

Table 2 is visualized and plotted by MATLAB as a 3D surface plot in Fig. 5.

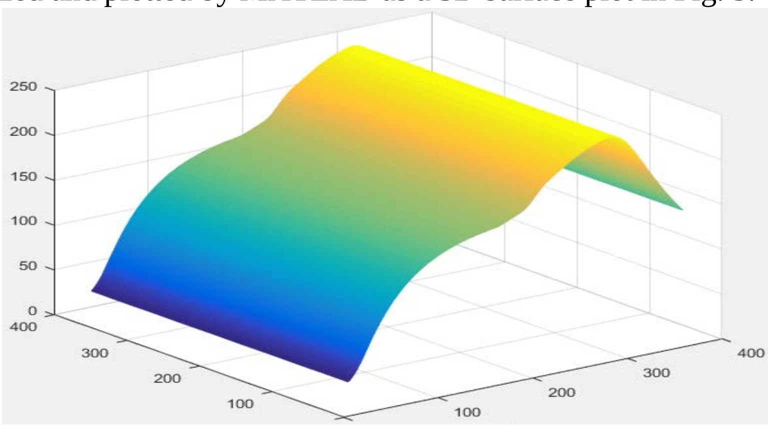

Figure 5. Variation of visualized furnace temperature profile under non-steady state thermal convection model

Among them, the X-axis indicates the time dimension of the board movement is divided into [0s, 400s], the Y-axis indicates the spatial dimension of the board is divided into [0cm, 400cm], and the Z-axis indicates the change in temperature.

Small temperature zone 3, 6, 7 midpoint and the end of the small temperature zone 8 at the center of the soldering area of the temperature of $\mu_{3c} = 123.323°C, \mu_{6c} = 162.8125°C, \mu_{7c} = 170.2375°C,$ $\mu_{8e} = 207.2599°C$ respectively.

4. Conclusion

This paper establishes a model of temperature change in the center of the welding area based on the thermal convection process to determine its temperature change at different moments and locations. First, based on Newton's law of cooling and the equation of specific heat capacity, the heat difference equation of discrete time is established. Secondly, through the law of energy conservation, the heat exchange equation is established for the center of the soldering area at different moments. After that, considering the existence of heating lag time during the processing of the circuit board in the furnace, the furnace temperature variation model of the center of the welding region in the time and space dimensions is obtained with the help of the second-order forward differential form. Finally, the integrated third category of heat exchange boundary conditions, the left and right boundaries of each small temperature zone and the gap between the small temperature zones are inscribed as well as the temperature settings of each temperature zone and the working requirements of the temperature sensor to form constraints on the small temperature zones and the center of the welding region.

Based on this, we time discretization process, according to the boundary conditions and initial value conditions, $\Delta t = 0.5s$ as a step in the time node layer by layer to solve for the temperature change in the center of the welding area and the corresponding furnace temperature curve, and determine the specific furnace temperature values at the midpoint of small temperature zones 3, 6, 7 and the end of small temperature zone 8.

References

[1] I. Evstatiev, T. Pencheva, P. Mashkov, Heat transfer modeling for soldering processes of SMD's to printed circuit boards using low inert infrared heaters, in: Proceedings of 28th IEEE ISSE Conference, 2005, pp. 112–117.

[2] G. Hanreich, J. Nicolics, Measuring the natural convective heat transfer coefficient at the surface of electronic components, in: Proceedings of IEEE IMTC Conference, 2001, pp. 1045–1050.

[3] D. Simion-Zanescu, P. Svasta, F. Streza, Self-teaching setup for reflow soldering process, in: Proceedings of 28th IEEE ISSE Conference, 2005, pp. 294–298.