ISSN: 2664-9640

Computer Simulation and Unsteady Partial Differential Governing Equation Study on Process Design of Rewind Furnace

Yifan Liu*, Lianda Yao, Shuqi Li and Gang Lu

Department of Electrical and Information Engineering, Shandong University of Science and Technology, Jinan, China;

* Corresponding Author

Abstract

By collecting the experimental data of rewind furnace, we established the unsteady PDE model.The temperature in the small temperature zone is distributed discretely, while the temperature change in the furnace cavity is continuous. In order to calculate the temperature between the small temperature zones with different temperatures, the heat conduction equation is considered to solve this problem.The model is based on Fourier's law and Newton's law of heat transfer experiment, and the specific heat capacity formula is derived by differentiating the heating process. The heat conduction coefficient at each moment after differentiating is calculated.Then the model is assigned to the set value of problem 1, and the function model of temperature change in the center of the welding zone with interval time t is obtained.The model was visualization by MATLAB toolbox, and the goodness of fit curve of 98.31% was obtained by Gaussian fitting. Then the derivative was obtained to verify that the slope k was in the range of (-1.57~1.92), the time over 217° C was 57s, the time between 150 ° C and 190 ° C was 66.5s, and the peak value was 240.59 ° C, all of which were in line with the process boundary, and the model was reasonable and reliable.

Keywords

Partial Differential Governing Equations, Monte Carlo simulation, Single objective nonlinear programming model.

1. Introduction

With the continuous development of the electronic information industry, the quality and efficiency of SMT (surface mount technology) technology [1] continue to improve. Reflow soldering technology, as the core process link of the SMT production line [2], directly affects the performance of surface mount products. In order to improve the production efficiency of products, it is necessary to continuously strengthen the research on reflow soldering technology. The efficiency of reflow soldering depends on the furnace temperature curve of reflow soldering. Therefore, in order to effectively improve its production level, it is necessary to continuously optimize the furnace temperature curve.

The contribution of this article is introduced below.

According to the collected process limits and transportation speed, the time of the circuit board in the reflow soldering process can be calculated based on this, and then the functional relationship of temperature change with time can be established, and then the CFtool data in MALAB can be fitted to determine the temperature change Interval and parameter range.

2. Model preprocessing

2.1. Analysis of model ideas

According to the process boundary and transportation speed collected, the time of circuit board in reflow soldering can be calculated accordingly, and then the function relation of temperature change with time can be established. After that, the temperature change interval and parameter range can be determined by fitting CFTOOL data in MALAB.

Think backwards.In order to obtain the maximum transmission speed of the conveyor belt, the shorter the time is, the faster the speed is under the condition of the same distance, and the data obtained can be guaranteed to be within the range of the process boundary by fitting.

2.2. Data preprocessing

In order to improve the quality of the data and make the data better adapt to the temperature change model, the missing data in the temperature sensor test were fitted.Because one-dimensional linear fitting has the characteristics of simplicity and accuracy. Therefore, the following interpolation formula is used to complete the missing values:

$$y_0 = 0.9527X + 17.93 \tag{1}$$

The goodness of fit of the equation is 0.8649, which has high accuracy.

The one-dimensional linear equation was used to complete the missing data of the temperature sensor before 30℃.

3. Model establishment and solution process

3.1. Interfurnace temperature analysis

The temperature of small temperature region is distributed discretely, while the temperature of furnace cavity changes continuously. In order to calculate the temperature between small temperature region with different temperatures, the heat conduction equation is considered to solve this problem, through Fourier experimental law [3]:

$$\mathrm{dQ} = -\mathrm{k(x, y, z)} \frac{\partial \mu}{\partial n} dSd \tag{2}$$

The heat conduction equation can be derived. Because the conveyor belt in the furnace can be regarded as one-dimensional, the one-dimensional form of the equation is

$$\frac{\partial u}{\partial t} = a^2 \frac{\partial^2 u}{\partial x^2} \tag{3}$$

Taking the reflow inlet as the origin and establishing the coordinate axis from left to right, the temperature between each small temperature zone of different temperature can be analyzed, and the temperature of the discrete small temperature zone can be fitted to the continuous furnace chamber temperature[4].

Taking the temperature changes in the small temperature zones in the 5th and 6th zones as an example, we can fit the discrete temperatures in the small temperature zones with different temperatures into continuous temperature change curves of the furnace chamber, and visualize the temperature changes between the 5th and 6th zones. The results are shown in the following figure.

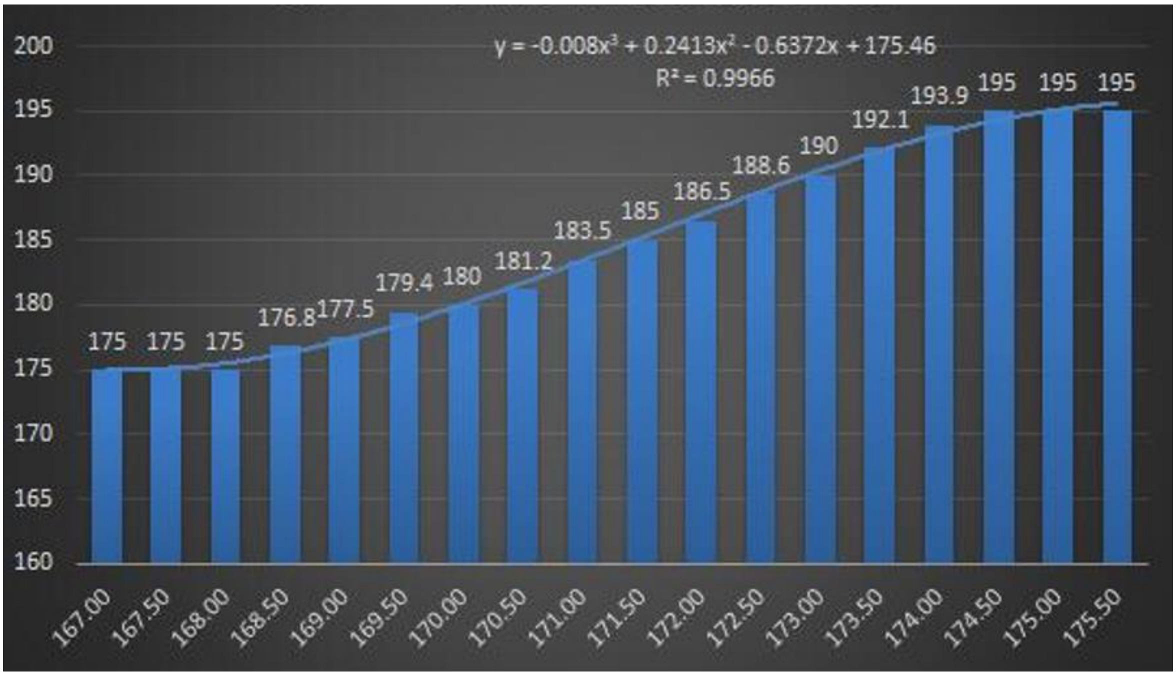

Figure 1: Temperature change curve of the 5th and 6th temperature zone in the sample.

From this example, we can see that the heat conduction equation has a good gradient effect when dealing with the changes between temperature regions, and the fitting curve is in line with the experimental data.

Therefore, this model can be extended to the analysis of temperature variation between other small temperature regions below.

3.2. Model establishment and solution

Based on the data of furnace temperature curve [6] given in an experiment, the unsteady partial differential governing equation can be established under the given new temperature limit value of each temperature zone, considering the process boundary factors comprehensively.

The model operation framework is shown in the figure below:

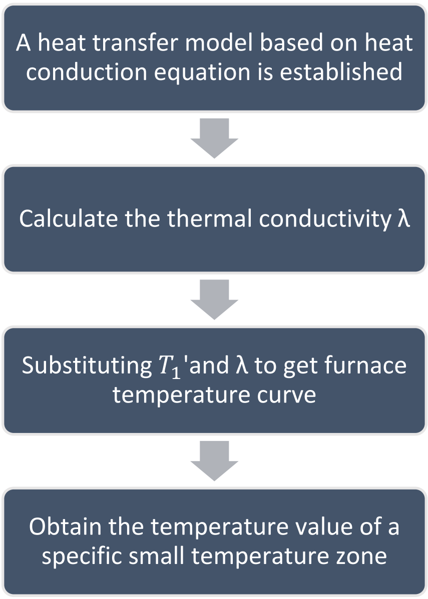

Figure 2: Model algorithm flow diagram

According to the collected data of furnace temperature curve in an experiment, the curve relation of temperature change with time in an experiment is obtained after data preprocessing.

Based on Fourier law, the heat transfer model based on the experimental law of heat conduction (Newton's law) can be established:

$$\lambda(T_1 - T_0)\text{dsdt} = dQ \tag{4}$$

At this time, the heat gained from the object flow to the medium is proportional to the temperature difference between the two, and the simultaneous specific heat capacity formula Q=cmΔt can be obtained by reasoning:

$$\lambda = \frac{CPL(T_2 - T_0)}{t(T_1 - T_0)} \tag{5}$$

Where λ is the thermal conductivity coefficient corresponding to the temperature at each moment. By substituting the experimental data in the attachment, the change curve of λ can be obtained.Because the molecules or atoms inside the object have been in a state of irregular movement, the movement of the molecules or atoms changes with the change of temperature, the thermal conductivity will change.Due to the large temperature difference in some small temperature areas, it is necessary to deal with the abnormal range value before drawing the λ change curve as shown in the figure below.

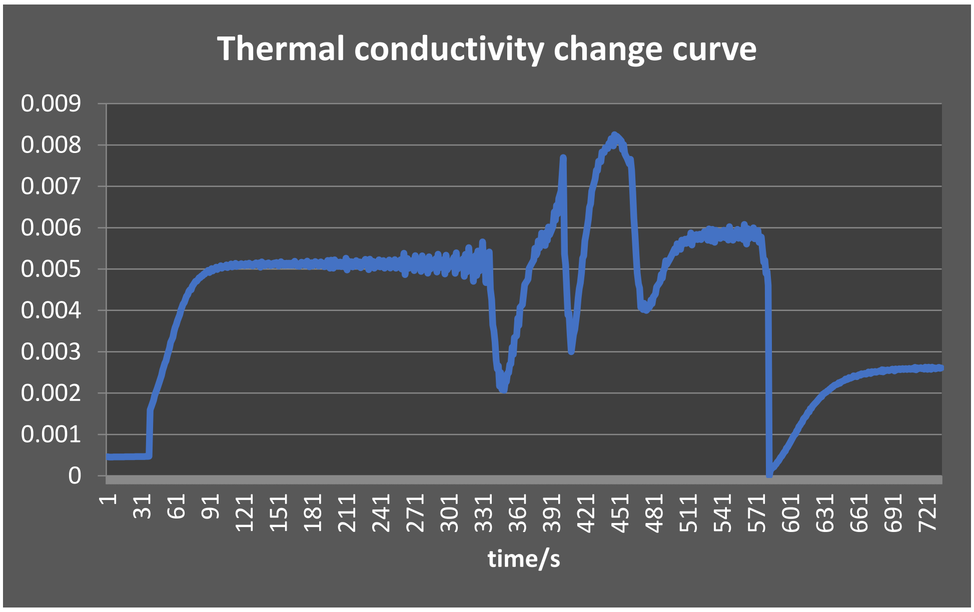

Figure :Thermal conductivity change curve

At this time, λ is a known quantity [7], and the center temperature of the welding area at the interval t can be derived:

$$T_2' = \frac{(T_2 - T_0)(T_1' - T_0{}')}{T_1 - T_0} + T_0' \tag{6}$$

Where T_1' is the temperature setting value of each temperature zone given by problem 1. After substituting, the center temperature of the welding area at the middle point and end of the low temperature zone and the corresponding furnace temperature curve can be obtained.

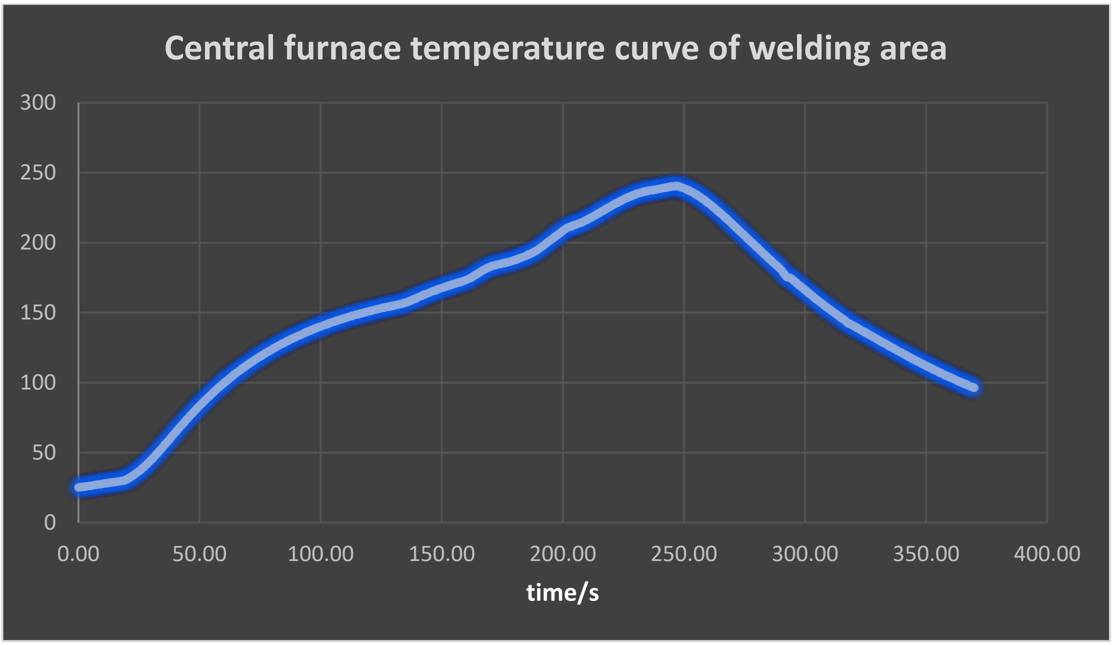

Figure 4:The center furnace temperature curve of the welding area

3.3. Plausibility test

In order to verify the rationality of furnace temperature curve, the furnace temperature curve and its function are obtained by cubic Gaussian fitting:

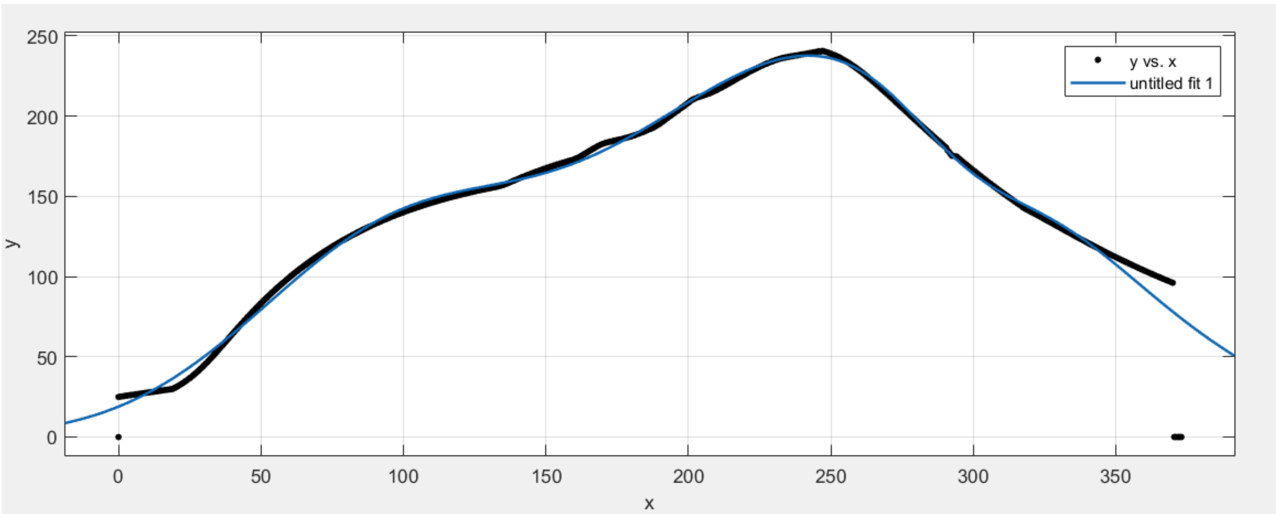

Figure 5: Fitting furnace temperature curve

$$f(x) = 99.87e^{-(0.014265x-1.333381)^2} - 32.67e^{-(0.030506x-9.072605)^2} + 239.4e^{-(0.008748x-2.180227)^2} \quad (7)$$

Its Adjusted R-square: 0.9831 has high reliability.

At this time, the time during the temperature rise process from 150ºC to 190ºC is in the range of [60s,120s], the time when the temperature is greater than 217ºC is in the range of[40s,90s], and the peak temperature is in the range of [240℃,250℃]. Meet the requirements of process boundaries.

After the derivative of the furnace temperature curve function is visualized, the derivative image of the furnace temperature function can be obtained as：

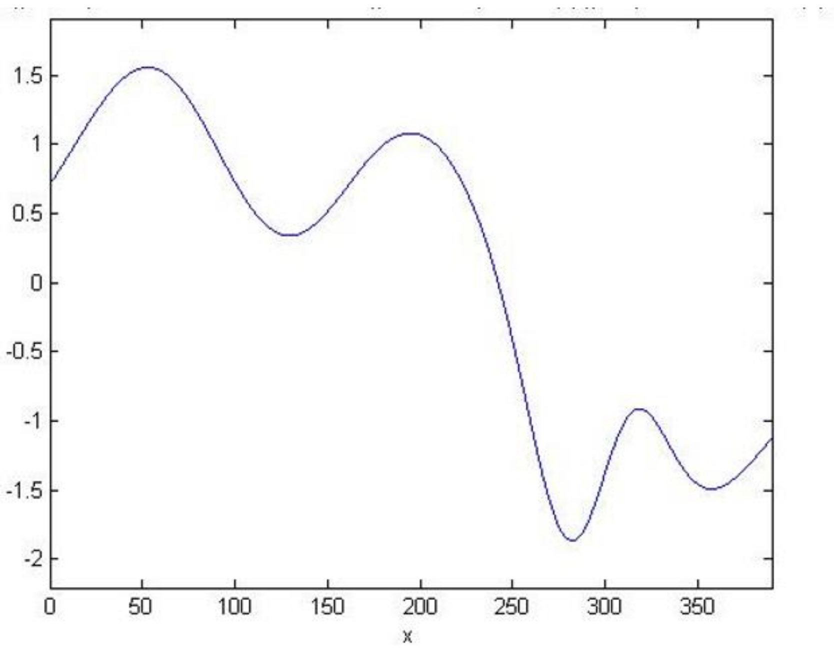

Figure 6: Derivative image of furnace temperature curve

According to the derivative image, the rising slope of temperature is between [-3℃/s, 3℃/s], which conforms to the setting of the temperature slope of the process boundary. In summary, the center temperature of the welding zone obtained by the furnace temperature curve is reasonable.

4. Conclusion

The furnace temperature curve with a goodness of fit of 98.31% was obtained by Gaussian fitting, and then the derivative was obtained. Finally, it was verified that the slope k was between (-1.57~1.92), the time over 217℃ was 57s, the time between 150 ° C and 190 ° C was 66.5s, and the peak value was 240.59 ° C, all of which were in line with the boundary of the process, and the model was reasonable and reliable. This model can be widely generalized.

Acknowledgments

Thanks to Zhu Qigang, Dong Yueyang, Liu Yang and Chen Junke from Shandong University of Science and Technology for their great support.

References

[1] Kan Kan, Yuan Zheng, Huixiang Chen, et al. Numerical simulation of transient flow in a shaft extension tubular pump unit during runaway process caused by power failure[J]. Renewable Energy, 2020.

[2] Kan Kan, Huixiang Chen, Yuan Zheng, et al. Transient characteristics during power-off process in a shaft extension tubular pump by using a suitable numerical model[J]. Renewable Energy, 2021.

[3] Gu Chaohao, Li Daqian: *Mathematical Physical Equation* (Higher Education Press, China 2012). p.7-49.

[4] Li Can, Gao Yandong, Huang Suyi: *Numerical Computation of Heat Conduction Problem Based on MATLAB [J].* (Journal of Huazhong University of Science and Technology (Natural Science Edition), China 2002(09)). p.91-93.

[5] Gao Jingang. *Optimization and control of reflow curve in surface mount production line..* (Doctoral dissertation, Shanghai Jiaotong University,China 2008).

ISSN: 2664-9640

[6] Alaya, Mohamed A.; Illés, Balázs; David, Bušek; Géczy, Attila. 2021. "Validation of Heat-Level Vapor Phase Soldering Process and Workspace Leakage Detection with Applied Pressure Sensors" *Appl. Sci.* 11, no. 4: 1755.
[7] Eftychiou, M.A.; Bergman, T.L.; Masada, G.Y. A Detailed Thermal Model of the Infrared Reflow Soldering Process. J. Electron. Packag. 1993, 115, 55.