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Reflow Process Parameters Analysis and Reliability Prediction Considering Multiple Characteristic Values

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Abstract. As a major step surface mount technology, reflow process is the key factor affecting the quality of the final product. The setting parameters and characteristic value of temperature curve shows a nonlinear relationship. So parameter impacts on characteristic values are analyzed and the parameters adjustment process based on orthogonal experiment is proposed in the paper. First, setting parameters are determined and the orthogonal test is designed according to production conditions. Then each characteristic value for temperature profile is calculated. Further, multi-index orthogonal experiment is analyzed for acquiring the setting parameters which impacts the PCBA product quality greater. Finally, reliability prediction is carried out considering the main influencing parameters for providing a theoretical basis of parameters adjustment and product quality evaluation in engineering process.

1 Introduction

In the era of rapid development for communication and information technology, electronic production has gradually become an indispensable necessity in daily life. To quickly adapt to market demand, electronic product design and manufacturing technology advances rapidly. Surface mount technology (SMT) has become the main way of electronic product manufacturing for its good coupling performance and high production efficiency. Industrial production usually aims at meeting customer requirements for product quality. As the main process in SMT, reflow profile quality reflects the final product quality directly in reflow soldering process [1]. During the reflow process, it is difficult for reflow profile to fully meet the customer's requirements. For this reason, we need to control the curve error within a reasonable range. Currently, the main method for reflow profile prediction is try and error, which requires that the operator has a wealth of experience [2]. Since the reflow process has a certain randomness which is affected by various uncertainties and the environment, it is necessary for reflow profile setting and analysis from the perspective of reliability. Considering the complexity of reflow process [3, 4], the paper conducts the study with the production examples from a company in Kunshan.

In order to investigate the influence on characteristic values, orthogonal design for parameters is carried out first to determine the main setting parameters and its influence. The study provides the basis for the reflow process parameter adjustment. Then the evaluation index for reflow profile characteristic values is defined to fit the reliability formula with Weibull distribution. The reliability

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of reflow profile characteristic values is also evaluated. Consequently, reliability analysis of reflow profile provides a theoretical basis for determining the characteristic value error range.

2 Reflow parameters analysis based on orthogonal experiment

2.1 Orthogonal Experimental Design

Orthogonal Experimental design is a design approach which arranges and analyzes multivariate experiment using normalized orthogonal [5]. Study of the reflow parameters impact on reflow profile and key indicators based on orthogonal experiment is able to determine the greatest impact parameter on all key indicators and their impact direction [6].

For the reflow process, there are many parameters to characterize the quality of reflow profile. Besides, each input parameter is the factors affecting the final quality of the reflow profile comprehensively. Therefore, the use of orthogonal experiment method can efficiently analyze the reflow process with multiple indicators.

2.2 Orthogonal Experimental Design

From the analysis, the setting parameters of the reflow process are the key factors to affect the reflow profile. So the setting parameters of eight oven zones((℃)) and the belt speed(m/min)marked A~J are selected as input parameters. Three levels are determined for each factor in the experiment. The characteristic values of reflow profile are peak temperature (℃)，soaking time(s), climbing time(s), melting time(s), cooling rate(m/min) and infiltration temperature (℃) marked K~P. The factors and their levels are listed in table 1.

Table 1. Factor levels

Factor / Level	Zone 1 (℃)	Zone 2 (℃)	Zone 3 (℃)	Zone 4 (℃)	Zone 5 (℃)	Zone 6 (℃)	Zone 7 (℃)	Zone 8 (℃)	Belt speed (m/min)
1	150	155	175	180	200	230	255	225	0.8
2	160	165	180	185	205	240	260	230	0.85
3	170	175	185	190	210	250	265	235	0.9

$L^{27}(3^{13})$ orthogonal table is used for arranging 27 sets orthogonal experiments. Then the experiments are carried out in an electronics production company in Kunshan. The experimental results are recorded in table 2.

Table 2. Orthogonal design& experimental results

No.	A	B	C	D	E	F	G	H	J	K	L	M	N	O	P
1	1	1	1	1	1	1	1	1	1	237.03	107.36	25.49	59.16	2.30	190.22
2	1	1	1	1	2	2	2	2	2	238.30	105.70	20.96	57.57	2.37	188.04
3	1	1	1	1	3	3	3	3	3	240.05	103.41	14.92	57.52	2.48	187.30
4	1	2	2	2	1	1	1	2	2	238.59	105.46	24.87	58.33	2.27	185.92
…	…	…	…	…	…	…	…	…	…	…	…	…	…	…	…
25	3	3	2	1	1	3	2	3	2	237.53	104.86	14.32	56.07	2.27	185.77

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26	3	3	2	1	2	1	3	1	3	239.90	104.51	22.12	54.84	2.35	188.86
27	3	3	2	1	3	2	1	2	1	238.47	105.41	22.95	57.61	2.27	185.54

2.3 Experimental analysis of multiple indicators

Range analysis aims at determining progression of factors based on range value calculated with mathematical statistics calculation method.

There are m factors in the experiment according to orthogonal table. Experimental results are recorded by $x1$, $x_2,\ldots, x_N$. Each factor has t levels, and n experiments are carried out for each level. Therefore, the total experiment time N is calculate by N=tn. It is known that

$$K_{ij} = \frac{T_{ij}}{n} \tag{1}$$

$$R_j = K_{ij(\max)} - K_{ij(\min)} \tag{2}$$

K_{ij} represents the mean value of experimental result for the jth column and the ith level. T_{ij} is the sum of experimental results for the jth column and the ith levels. $K_{ij\,(\max)}$ is the maximum K_{ij} value in the jth column. $K_{ij(\min)}$ is the minimum K_{ij} value in the jth column. c is range value of the jth column.

Range analysis is capable of studying the degree of setting parameters influence on the characteristic values. Thus, range analysis is implemented on orthogonal test results in table 2. K value and R value of each characteristic value is computed by formula (1) and formula (2). According to range analysis, the main factors affecting the peak temperature is temperature of zone 7, temperature of zone 6, belt speed and temperature of zone 4 in succession; the main factors affecting the soaking time is belt speed, temperature of zone 6, temperature of zone 3, and temperature of zone 4 in succession; the main factors affecting the climbing time is temperature of zone 6, belt speed, temperature of zone 5 and temperature of zone 4 in succession; the main factors affecting the melting time is belt speed, temperature of zone 6, temperature of zone 8, and temperature of zone 7 in succession;the main factors affecting the cooling rate is temperature of belt speed, zone 8, temperature of zone 7 and temperature of zone 2 in succession; the main factors affecting the infiltration temperature is temperature of zone 6, temperature of zone 5, temperature of zone 7 and temperature of zone 8 in succession. Analysis of K value is shown in figure 1.

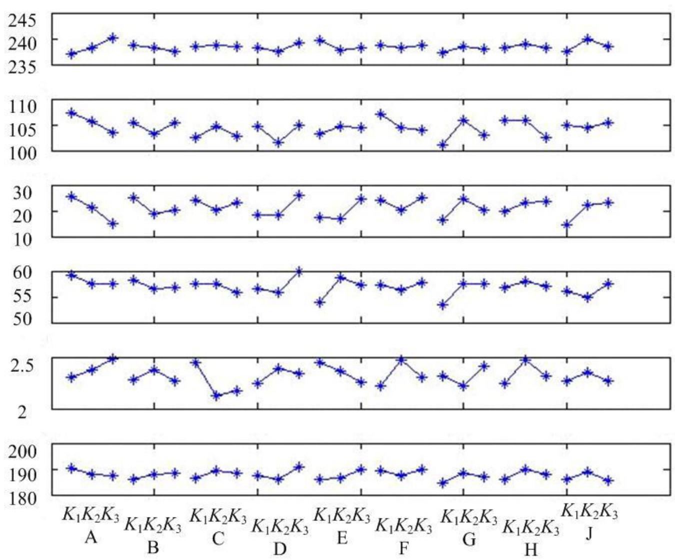

Figure 1. Analysis of K-value

It is known from figure 1 that the output distribution shows a range of differences with different factor influence degree. The factor with a relatively large difference is corresponding to the important one, which is consistent with the characteristic values in the oven zone accordingly during the reflow process. From this point of view, we conclude that the analyzed result meets the actual production process. To sum up, belt speed, zone 7 and zone 8 are the major factors to influence the reflow profile, which needs to monitor particularly in the production process. During the production process, the above findings may provide a theoretical reference for the production of parameter adjustment.

3 Reliability of characteristic value index

The sample No. 2Q012D000-600-GB/T-A-HF is used in the experiment for analysis. The setting parameters are listed in table 3. In the experiment, four major parameters are used as random variables for reliability analysis. From the above analysis, the major parameters are temperature of zone 4, zone 6, zone 7 and belt speed. Due to differences in the production conditions, errors are produced for various parameters inevitably, which affects product reliability significantly. For analyzing the randomness of parameters, the above major parameters are supposed as random variables which obey normal distribution as table 4.

Table 3. Temperature setting of reflow soldering oven

Oven zone	#1	#2	#3	#4	#5	#6	#7	#8	#9	#10
Setting temperature/℃	160	165	180	185	205	240	260	230	60	20

Table 4. Mean and standard deviation of all variation

Varible	T_4(℃)	T_6(℃)	T_7(℃)	v (m/min)
Mean value	185	240	260	0.85
Standard deviation	2	2	2	0.01

The probability level is chose as $p_1 = 0.01$、$p_2 = 0.5$、$p_3 = 0.99$. Then the sample value is calculated according to Box-Behnken matrix sampling method [7]. Furthermore, characteristic value is calculated with BP-Neural Network. For evaluating the fitting reflow profile comprehensively, reflow profile quality evaluation index is defined as equation (4). According to the definition of evaluation index, it is known that the smaller $f(x)$ represents the product meeting customer requirements better. The calculated results are listed in table 5. xi represents the reliability of evaluation index.

$$f\left(x_i\right)=\sum_{k=1}^{P} L\left(y_k\right) \tag{3}$$

Table 5. Sample points of Box-Behnken method and data of reliability tests

Sample	T_4(℃)		T_6(℃)		T_7(℃)		v(m/min)		x_i
	Level	Value	Level	Value	Level	Value	Level	Value	
1	p_2	185	p_2	240	p_2	260	p_2	0.85	0.0353
2	p_1	180.34	p_1	235.34	p_2	260	p_2	0.85	0.0307
3	p_3	189.66	p_1	235.34	p_2	260	p_2	0.85	0.0121
4	p_1	180.34	p_3	244.66	p_2	260	p_2	0.85	0.0720
5	p_3	189.66	p_3	244.66	p_2	260	p_2	0.85	0.0405
6	p_2	185	p_2	240	p_1	255.34	p_1	0.827	0.0235

7	p_2	185	p_2	240	p_3	264.66	p_1	0.827	0.0417
8	p_2	185	p_2	240	p_1	255.34	p_3	0.873	0.0333
9	p_2	185	p_2	240	p_3	264.66	p_3	0.873	0.0531
10	p_1	180.34	p_2	240	p_2	260	p_1	0.827	0.0416
11	p_3	189.66	p_2	240	p_2	260	p_1	0.827	0.0195
12	p_1	180.34	p_2	240	p_2	260	p_3	0.873	0.0565
13	p_3	189.66	p_2	240	p_2	260	p_3	0.873	0.0285
14	p_2	185	p_1	235.34	p_1	255.34	p_2	0.85	0.0304
15	p_2	185	p_3	244.66	p_1	255.34	p_2	0.85	0.0523
16	p_2	185	p_1	235.34	p_3	264.66	p_2	0.85	0.0264
17	p_2	185	p_3	244.66	p_3	264.66	p_2	0.85	0.0688
18	p_1	180.34	p_2	240	p_1	255.34	p_2	0.85	0.0403
19	p_3	189.66	p_2	240	p_1	255.34	p_2	0.85	0.0175
20	p_1	180.34	p_2	240	p_3	264.66	p_2	0.85	0.0896
21	p_3	189.66	p_2	240	p_3	264.66	p_2	0.85	0.0305
22	p_2	185	p_1	235.34	p_2	260	p_1	0.827	0.0169
23	p_2	185	p_3	244.66	p_2	260	p_1	0.827	0.0477
24	p_2	185	p_1	235.34	p_2	260	p_3	0.873	0.0248
25	p_2	185	p_3	244.66	p_2	260	p_3	0.873	0.0644

MATLAB toolbox is applied for parameters estimation. The estimative values are

$$\beta=20256，\eta=0.045$$

K-S test is applied for testing the fitness of parameters estimation. The observed value $\tilde{D}_n$ is

$$\tilde{D}_n = \max\left\{\tilde{d}_i\right\} = 0.1108$$

Significance level is taken as α=0.10, so $D_{n,\alpha}$=0.2377. Since it is known that $\tilde{D}_n < D_{n,\alpha}$, the hypothesis H_0 is acceptable. Therefore, the reliability of evaluation index obeys the Weibull distribution, which is shown as follows.

$$R(x) = \exp\left[-\left(\frac{x}{\eta}\right)^{\beta}\right] = \exp\left[-\left(\frac{x}{0.045}\right)^{2.256}\right]$$

The fitting curve of reliability is shown in figure 2. It is obvious that the smaller evaluation index is, the higher the reliability is.

The fitting equation of reflow profile quality evaluation index reliability has significant practical value. On one hand, when the evaluation index is calculated according the characteristic value of the reflow profile, the reliability of the evaluation index can be calculated. Furthermore， reliability of product can be acquired quantitatively as well. On the other hand, precision condition of characteristic value acquired by custom can also be determined with the index reliability analysis.

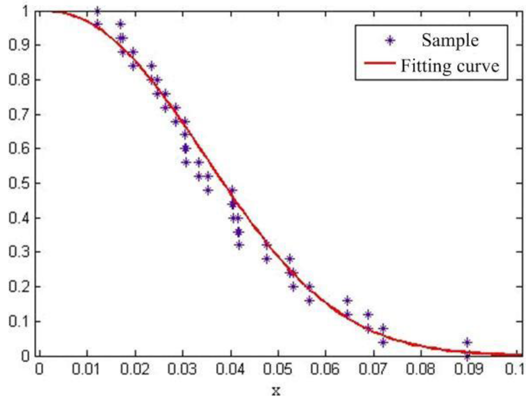

Figure 2. Fitting curve of reliability

4 Conclusions

(1) Considering the effect of characteristic values of reflow profile comprehensively, characteristic values and their influence degrees under different factor levels are calculated based on orthogonal design. The study result shows that the major influences on the reflow profile are belt speed, temperature of zone 6 and zone 7, which need to be monitored seriously.
(2) Reflow profile quality evaluation index is defined to calculated the characteristic value. Weibull distribution is applied for fitting the equation of index reliability. The reliability equation is capable of acquiring the product reliability with required evaluation index.

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